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Capelin in SA2 + Div. 3KL during 1999

État du capelan de la sous-zone 2 et des divisions 3KL en 1999

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Abstract

This document contains a number of discrete research results which were discussed during the 2000 assessment of capelin in SA2 + Div. 3KL. These results are arranged in eleven chapters and include results of studies on inshore capelin spawners, the inshore fishery, beach and demersal spawnings, 0-group and larval capelin, offshore capelin, trawl/acoustic catchability, capelin lengths and yearclass strength (as determined using a multiplicative model). In additional chapter (Chapter 6) provides data pertaining to capelin in Div. 3Ps.

Résumé

Ce document présente les résultats de recherches discrètes discutés durant l'évaluation de l'état du capelan de la sous-zone 2 et des divisions 3KL tenue en 2000. Divisés en onze chapitres, ils incluent les résultats d'études des reproducteurs du capelan côtier, de la pêche côtière, de la fraie sur les plages et dans les eaux de fonds, des larves et du groupe d'âge 0, du capelan hauturier, de la capturabilité au chalut et au relevé acoustique, des longueurs et des effectifs des classes d'âge (déterminés à l'aide d'un modèle multiplicatif). Un chapitre additionnel (chapitre 6) contient des données sur le capelan de la division 3Ps.

Results of a Telephone Opinion Survey of Fixed Gear Capelin Licence Holders for 1999

by

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Introduction

A questionnaire was used to quantitatively evaluate biological and fishery-related information obtained from capelin (Mallotus villosus) fishers in 1999. The questions were developed to supplement information collected by the research logbook and beach sampling programmes and to quantify to some extent the impressions of fishers on the status of the capelin stock in Div. 3KL. The questionnaire has not changed since 1997.

Methods

The survey population size of 1546 (3L: 755, 3K: 791) was defined as all capelin fixed gear (traps and beach seines) fishers licensed to fish capelin in NAFO Div. 3L and 3K in 1999. A list of names and telephone numbers was provided by Resource Management Division, Fisheries and Habitat Management Branch, Fisheries and Oceans. Employing a simple random sampling design and an expected response rate of 85%, a sample population with 205 names was chosen to achieve a ±7% margin of error with 95% confidence intervals (Gower and Kelly 1993). The sampling statistics do not apply to the comments presented in Table 5 nor to the geographical comparisons in Table 4. The survey was conducted by telephone interview.

Telephone interviews commenced October 6, 1999 and were completed on November 16, 1999. Interviewers were unable to contact 30 individuals who were part of the sample population. Of these 10 could not be contacted despite five attempts to do so, 6 had no telephone in service (disconnected, wrong number, no telephone number), two declined to participate, and 12 did not fish. The 175 completed questionnaires represent an 85% response rate.

For questions 1, 2, and 7a that measure a scaled response, a two-tailed Kolmogrov-Smirnov Test was used to determine the statistical similarity of the distribution of responses between two years (Siegel 1956).

Results and Discussion

Abundance Questions

Three questions (Appendix A) comparing abundance of capelin in 1999 to previous years were asked in the survey. Most respondents indicated that capelin abundance in 1999 in their area was low (Fig. 1). Statistical paired comparisons suggest that 1994 was the lowest response and significantly different from all the subsequent years (Table 1). Similarly, 1996 was significantly different from the other years and is the highest response. The years 1995, 1997, 1998, and 1999 are not significantly different from each other (Table 1).

The trends in the mean and median values corresponded to the Kolmogrov-Smirov comparison of distributions.

Year	1994	1995	1996	1997	1998	1999
Mean	2.5	3.4	5.4	3.8	4.1	4
Median	1	3	5	4	4	3

Estimates of capelin abundance obtained in 1998 were similar to what respondents recalled for that year when asked one year later in 1999 (Fig. 2, Table 2). Statistical comparisons for how well abundance is estimated one year later gives mixed results. The 1994 and 1995 abundances are significantly different depending on when estimates were made (Table 2). In contrast there were no significant differences in the 1996, 1997, and 1998 abundance estimates that were made one year later. When given three options in question 3 (Appendix A) respondents clearly indicated that capelin abundance in 1999 was lower than when they first started to fish capelin (Fig. 3). This response has held firm for all surveys. Generally most respondents considered capelin abundance to be low and similar to 1998.

Spawning Questions

Questions 4-13 (Appendix A) relate to spawning. According to respondents capelin in 1999 occupied a small proportion of the available spawning beaches (Fig. 4). The proportion of respondents reporting 'no spawning' was 35%. The responses in the 1-5 beaches category is the same as in 1998 (Nakashima and Clark 1999) and most responses were at the low end of the range. Whether capelin spawned on less, the same, or more beaches in 1999 compared to 1998 was variable and somewhat related to location (Fig. 5). The intensity of spawning in 1999 (Fig. 6) shows a bimodal response and is similar to 1998. Spawning intensity in 1999 was statistically similar to 1995, 1997, and 1998 (Table 3). Similar to capelin abundance, spawning intensity in 1994 was low and significantly different from all other years and was high in 1996 and significantly different from all other years (Table 3). Spawning intensity between 1999 and 1998 was variable (Fig. 7). Egg densities at Bellevue Beach in 1999 were slightly lower than in 1998, however almost all the eggs were deposited during one spawning session in 1999 (Nakashima and Slaney 2000a). Respondents felt spawning on beaches in 1999 was similar to 1998.

Reports of off beach spawning continue to be in excess of 50% in 1999 (Fig. 8). Non-responses remain high at almost 30%. The historical view of capelin spawning off beaches is similar to 1994 (Fig. 9). The 112 persons who responded in the affirmative to question 8 were asked to give reasons why capelin may have spawned in deeper water in 1999 (Appendix A: question 9). The most frequent response was warmer water temperatures in deeper water (40%). Other possibilities suggested were the presence of predators (e.g. humans, seagulls) driving capelin away from beaches (8%), low capelin abundance (4%), no cod to drive capelin ashore (3%), dirty water (2%), and cold water (1%). Approximately 14% said capelin in their area always spawned in deep water which is higher than the 8% in 1998. The remaining 20% gave no response.

The time when spawning began in 1999 was still delayed compared to the 1980s, however spawning is occurring earlier. The distribution of times was later than in 1996 but earlier than in 1994 (Fig. 10). Of those answering question 11a who recalled when spawning began in 1999, the majority suggested late June to late July with most

respondents favouring early July to mid July (Fig. 10). Comparing the start of the spawning season in 1999 to 1998 in question 11b most respondents who expressed an opinion indicated that it was the same or earlier (Fig. 11). Compared to when fishers first started fishing capelin, spawning times in 1999 were later or the same (Fig. 12). This is the first time since the survey began in 1994 that the majority indicated spawning times were the same as when they first started fishing. Spawning began in late June and finished by mid July at Bellevue Beach, Trinity Bay in 1999 (Nakashima and Slaney 2000a).

The size of females was small (31%) or average (46%) with some reports of large females (7%) (Fig. 13). Mean lengths and weights of capelin collected at Bellevue Beach indicated fish were getting larger but still not as large as in the 1980s (Nakashima and Slaney 2000a).

Questions on the Fishery

Almost all licensed respondents (90%) intended to fish capelin in 1999 and 27% of them set out fishing gear or searched for capelin. Of the 42 respondents who fished in 1999, 20 used one trap, 14 used two traps, 1 fished more than 2 traps, 2 used trap(s) and a beach seine, and 7 used a beach seine. Only 26% who fished had no landings in 1999 (Fig. 14) and average reported landings were 117,500 lbs (53,300 kg). The majority reported discards of less than 25,000 lbs (11,340 kg) (Fig. 15). Combining estimates of landings and discards the average catch per telephone respondent in 1999 was 177,900 lbs (80,700 kg) (Fig. 16) which is double the average catch from research logbook estimates (44,500 kg, Nakashima and Slaney 2000b). Table 4 compares the average catch per fisher reported in the opinion survey and the research logbook program by fishing area. The opinion survey always had the higher catch rate. The research logbook data were only for capelin traps. Most of the discarded capelin were released alive (Fig. 17), comparable to what was reported in research logbooks. The reasons for discarding were low percentage of females (19%), redfeed (19%), small fish (19%), problems with buyers and selling capelin (11%), over ripe females (11%), capelin mixed with herring (11%),capelin mixed with cod (4%), catch too small amount to land (4%), and capelin released because of gear damage (4%). Research logbook results suggest the presence of redfeed, low percentage of females, and no markets as the major reasons capelin were

discarded from traps (Nakashima and Slaney 2000b). Discarding in 1999 was reported to be lower than in previous years (Fig. 18). Discarding rates for traps were low in 1999 (Nakashima and Slaney 2000b). Of those who fished, 63% reported bycatches of a few pounds to several thousand pounds. The most frequent bycatch species based on estimated weight were herring (70%), cod (20%), and small cod (10%). Squid, salmon, and rock cod were also mentioned. Of these 81% were released alive.

Questions on Climate and Ocean Conditions

The sample population was asked question 24 (Appendix A) pertaining to general weather and oceanic conditions during the summer of 1999. Wind conditions in the summer of 1999 were considered light or favourable(53%) or moderate (26%). Air temperatures were reported to be mainly warm (68%), or hot (23%). The summer was mainly sunny (83%) or half sunny and half overcast (13%). Ice was not a concern in 1999. Thirty-eight percent reported icebergs in their area. Water temperatures were generally warm (71%) or average (23%). Reports of cool (3%) water temperatures were rare. Overall weather conditions were considered to be good (59%) to excellent (25%) for fishing throughout the region.

Comments by Respondents

At the end of the telephone interview each of the 175 respondents were provided the opportunity to make comments. The range of topics covered most aspects of capelin biology and the fishery and also on other fisheries. The comments relative to capelin have been summarized in Table 5. In many instances more than one comment was given but only one comment per respondent was reported in Table 5.

Demographics of the Sample Population

All respondents were asked questions 25-28 to characterize the sample population of fixed gear fishers and to be able to relate in subsequent analyses responses to areas fished and experience in the fishery. The distribution of responses to question 25 shows the number of years of involvement in the capelin fishery (Fig. 19). Fishing vessel lengths varied from 17 to 60 feet with 81% less than 36 feet (Fig. 20). Estimated vessel capacity for capelin was less than 30,000 lbs (13,600 kg) for 76% of the

fishing fleet involved in the fixed gear capelin fishery (Fig. 21). Most licensed fixed gear capelin fishers are between 35 to 55 years of age (Fig. 22). The average age was 46 years. Average vessel capacity (24000 lbs or 10,900 kg) and vessel length (32 ft) of the fleet and the age structure of the licence-holders are comparable to previous surveys. The highest proportion of respondents was from Notre Dame Bay with the fewest fishers in the sample population from the Southern Shore and St. Mary's Bay (Fig. 23). The distribution of responses from Div. 3KL in the sample population is similar to other years and proportional to the survey population.

Summary

Results from the telephone survey of fixed gear capelin fishermen provided observations on beach spawning, local capelin abundance, fishing activities, and summer weather conditions. In 1999 most respondents indicated that capelin spawned later, spawned on fewer beaches than in the past, and spawned subtidally away from beaches more so than in the 1980s. Abundance and spawning intensity were comparable to 1995, 1997, and 1998. Most licensed fishers intended to fish in 1999 but only 27% actually put their gear in the water or searched for capelin. Commercial fixed gear fishing occurred in all areas of Div. 3KL except the Southern Shore and St. Mary's Bay. The weather was generally considered favourable for fishing and water temperatures were considered warmer than normal. Overall respondents felt capelin abundance and spawning on beaches in 1999 was similar to 1998 but continues to be lower than in the 1980s. The results of this survey as applied to Div. 3KL represent the opinions of the survey population at the time the survey was conducted with a ±7% margin of error 19 times out of 20.

Acknowledgements

Morris Clark and Barry Slaney conducted the telephone interviews. Our appreciation to the individuals who took the time to share their knowledge with us. M.Y. Farrell assisted in the preparation of the manuscript.

References

Gower, A., and K. Kelly. MS 1993. How big should the sample be? Social Survey Methods Division, Statistics Canada. 14p. (Mimeo).

Nakashima, B. S. 1995. Results of a survey of 1994 fixed gear capelin licence holders. pp. 4-24. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70.

1997. Results of a telephone survey of 1996 fixed gear capelin licence holders. pp. 28-41. In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 97/29.

Nakashima, B. S. and M. C. Clark. 1999. Results of a telephone survey of 1997 fixed gear capelin licence holders. pp. 1-37. In: Anon. Capelin in SA2 + Div. KL. CSAS Res. Doc. 99/206.

Nakashima, B. S. and B. W. Slaney. 2000a. Spawning and early development of capelin (Mallotus villosus) at Bellevue Beach, Trinity Bay in 1999. pp. . In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 00/ .

Nakashima, B. S., and B. W. Slaney. 2000b. The 1999 inshore capelin (Mallotus villosus) fishery in NAFO Div. 3KL. pp. . In: Anon. Capelin in SA2 + Div. KL. CSAS Res. Doc. 00/ .

Siegel, S. 1956. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill New York pp.127-136.

Table 1. Comparison of capelin abundance (Question 1) using a Kolmogorov-Smirnov test.

	1994	1995	1996	1997	1998
1995	.001				
1996	.001	.001			
1997	.001	ns	.001		
1998	.001	ns	.001	ns	
1999	.001	ns	.001	ns	ns

Table 2. Comparison of capelin abundance with time using a Kolmogorov-Smirnov test.

	1994	1995	1996	1997	1998
1995	.001				
1996		.05			
1997			ns		
1998				ns	
1999					ns

Table 3. Comparison of capelin spawning intensity (Question 7a) using a Kolmogorov-Smirnov test.

	1994	1995	1996	1997	1998
1995	.01				
1996	.001	.001			
1997	.01	ns	.001		
1998	.001	ns	.05	ns	
1999	.001	ns	.001	ns	ns

Table 4. Catch rates (catch (t) per fisher) by fishing area estimated from the opinion survey and research logbooks.
Sample sizes are given (N).

Fishing area	Opinion		Logbook	
	N	Catch rate	N	Catch rate
White Bay	10	185.4	6	50.5
Notre Dame Bay	7	31.1	1	27.0
Bonavista Bay	7	21.1	3	21.6
Trinity Bay	13	74.5	9	52.9
Conception Bay	5	40.1	1	18.7
Southern Shore	0	-	0	-
St. Mary's Bay	0	-	0	-

Table 5. Summary of comments pertinent to capelin or the capelin fishery.

Comment	Number of responses	% response
No capelin/scarce	31	17.7
Lots outside and after quota closed		
Most capelin and biggest after quota closed		
Not much and small	5	2.9
Good size and abundant	12	6.8
Fair amount/abundant and small		
Small	1	0.6
Bay stocks of large capelin gone, small offshore ones left		
Capelin only in a few spots		
Capelin around long time		
Capelin deep not come to land	16	9.1
Later coming in every year		
Spawning on unusual beaches		
Spawning night time only	1	0.6
Spawning in fall (Sept.)		
Spawning later; all sizes mixed		
Caught/destroyed by seiners/longliners	4	2.3
Capelin are overfished	2	1.1
Fishery should be closed	18	10.3
Cod closed; capelin should be closed	7	4.0
Should not be destroyed for nothing/low price	13	7.4
Low abundance, close fishery	4	2.3
Leave alone for a while	17	9.7
Need better monitoring		
IQ system	2	1.1
Need bigger quota	1	0.6
Opened too early		
Opened too late	5	2.0
Buyers not interested in buying	4	2.3
No comments	32	18.3

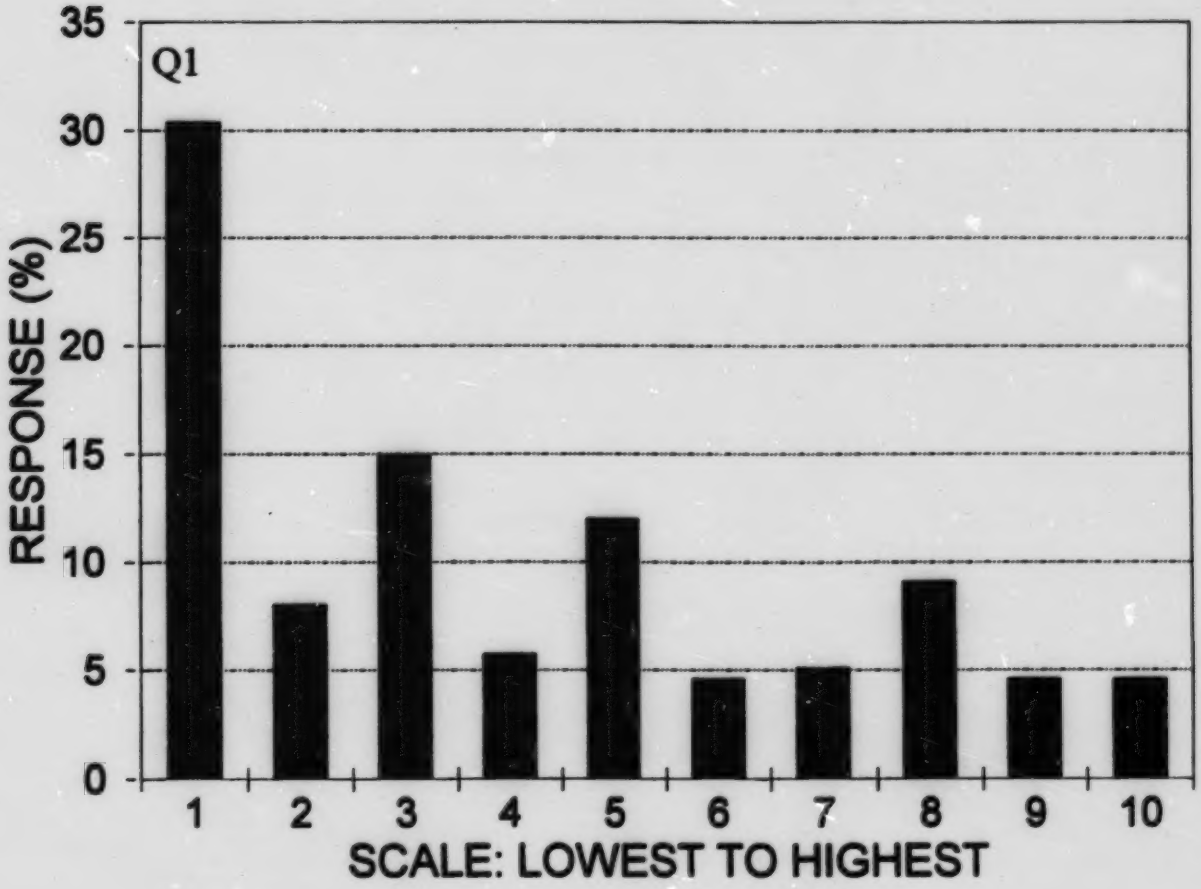

Fig. 1. Response to question 1 on the abundance of capelin in 1999.

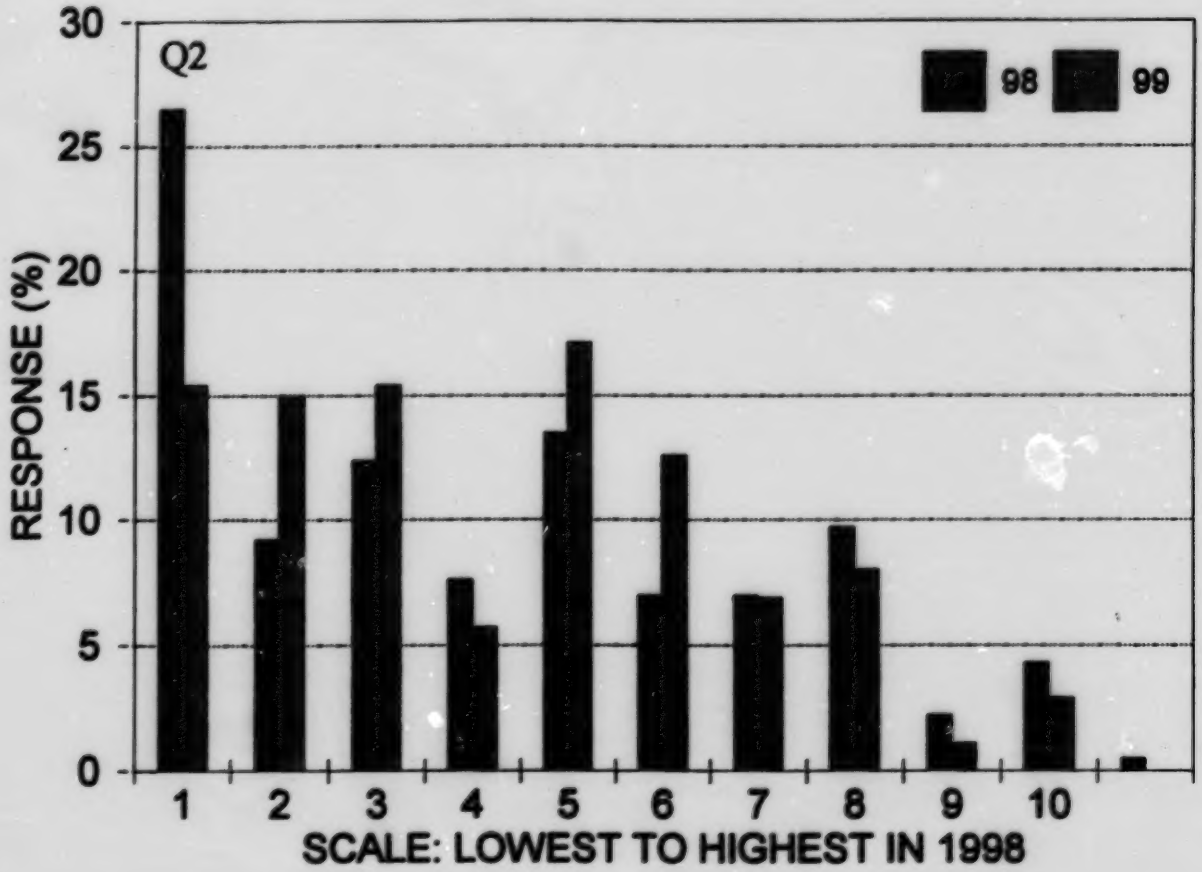

Fig. 2. Impression of capelin abundance in 1998 from the 1998 (Nakashima and Clark 1999) and 1999 surveys.

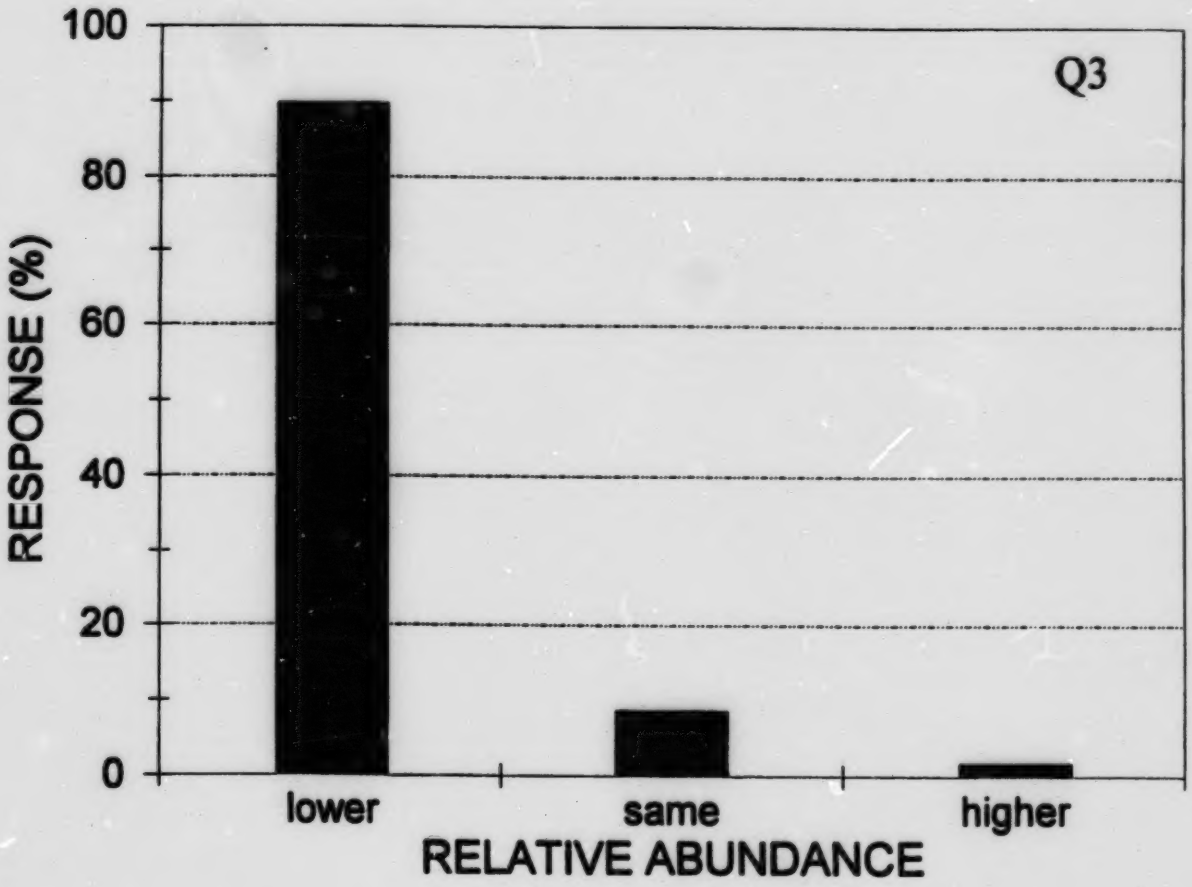

Fig. 3. Response to question 3 concerning abundance in 1999 compared to first started fishing. No answer given (na).

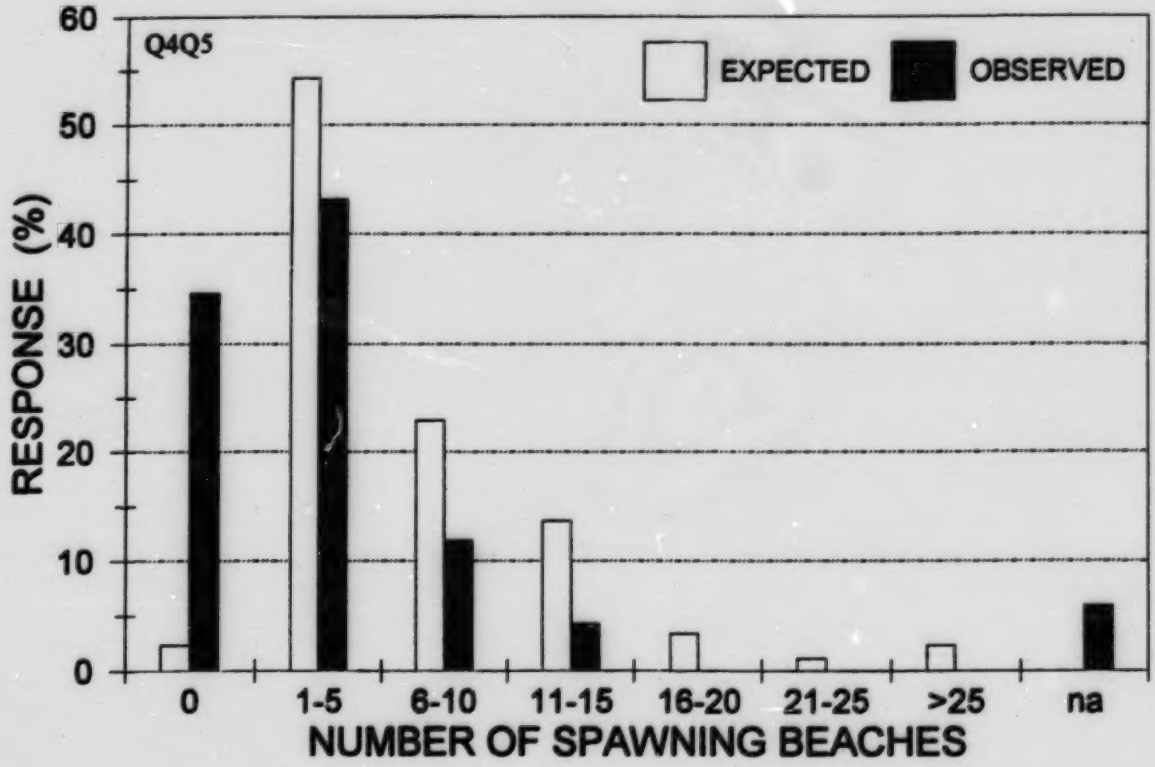

Fig. 4. Comparison of the number of beaches capelin spawned on in 1999 to the available beaches. No answer given (na).

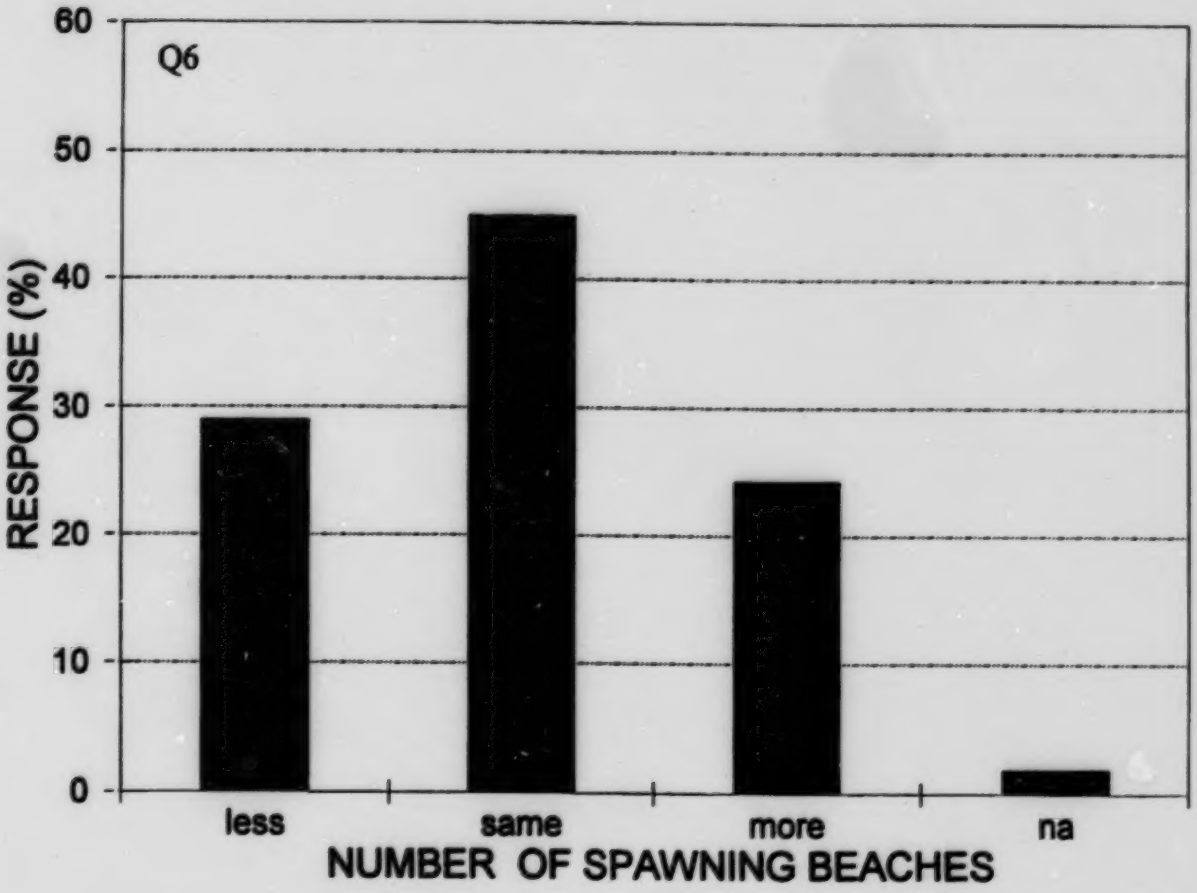

Fig. 5. Response to question 6 concerning the relative number of spawning beaches occupied in 1999 compared to 1998. No answer given (na).

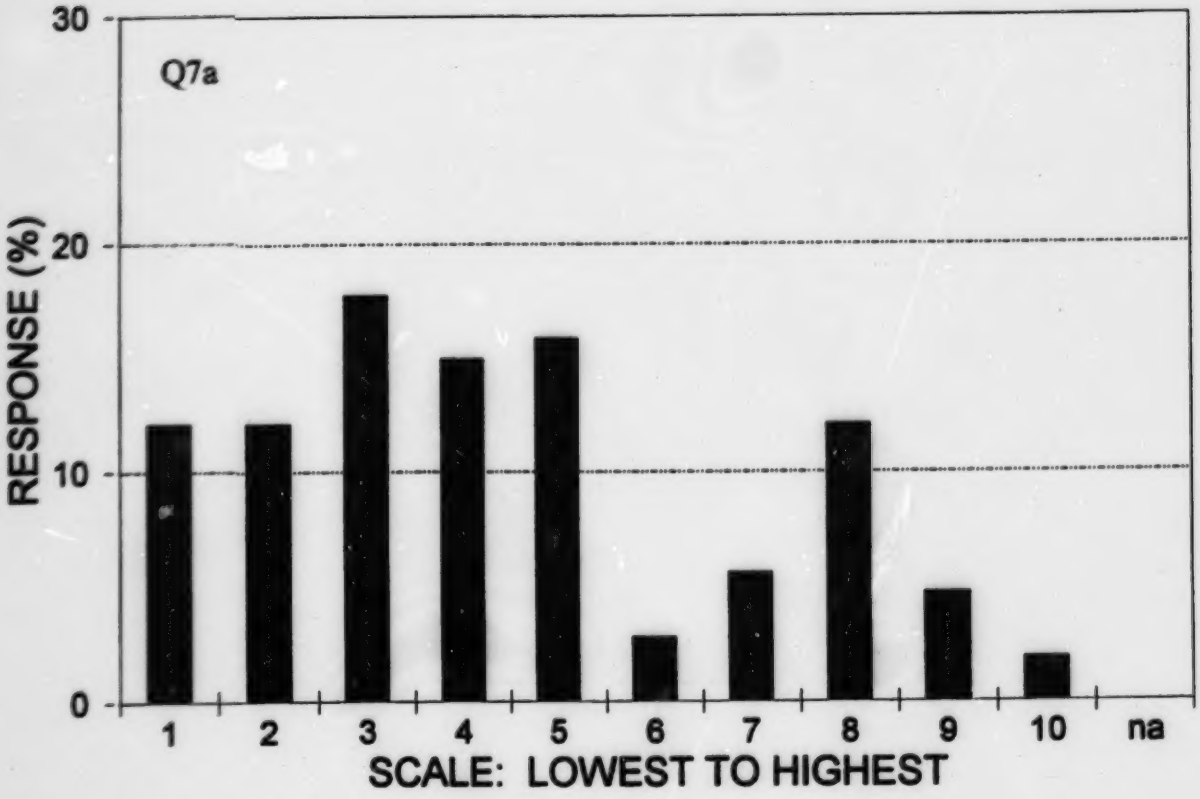

Fig. 6. Response to question 7a concerning the intensity of spawning on an increasing scale of 1 to 10 in 1999. No answer given (na).

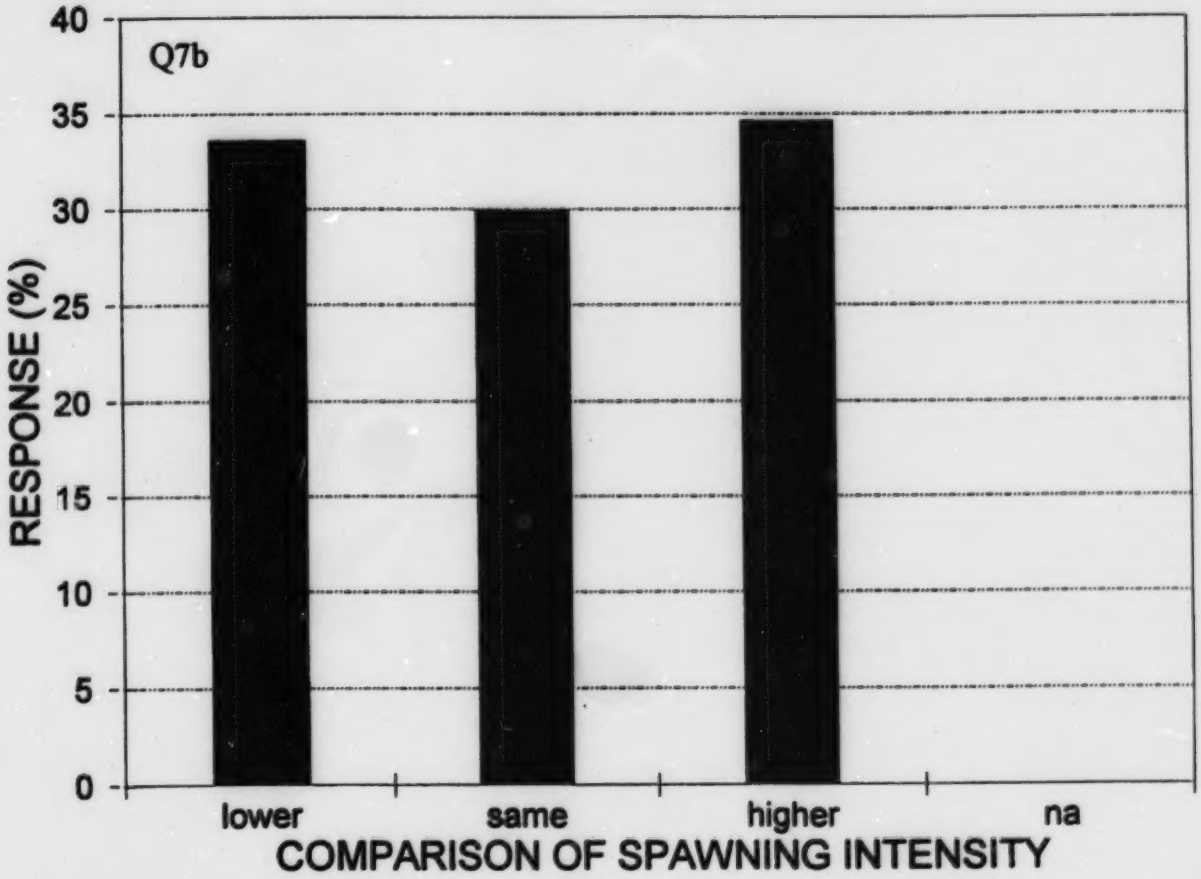

Fig. 7. Response to question 7b comparing the spawning intensity in 1999 relative to 1998. No answer given (na).

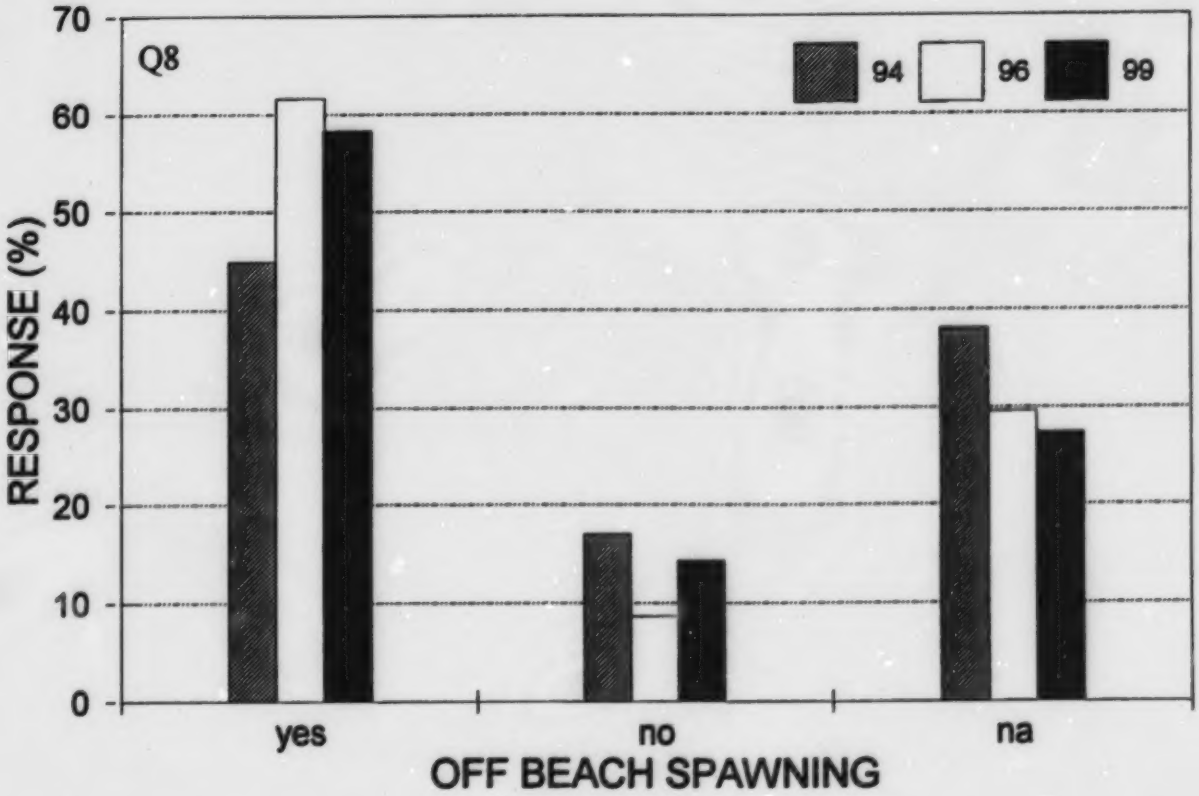

Fig. 8. The extent that off beach spawning occurred in 1994, 1996 and 1999. No answer given (na).

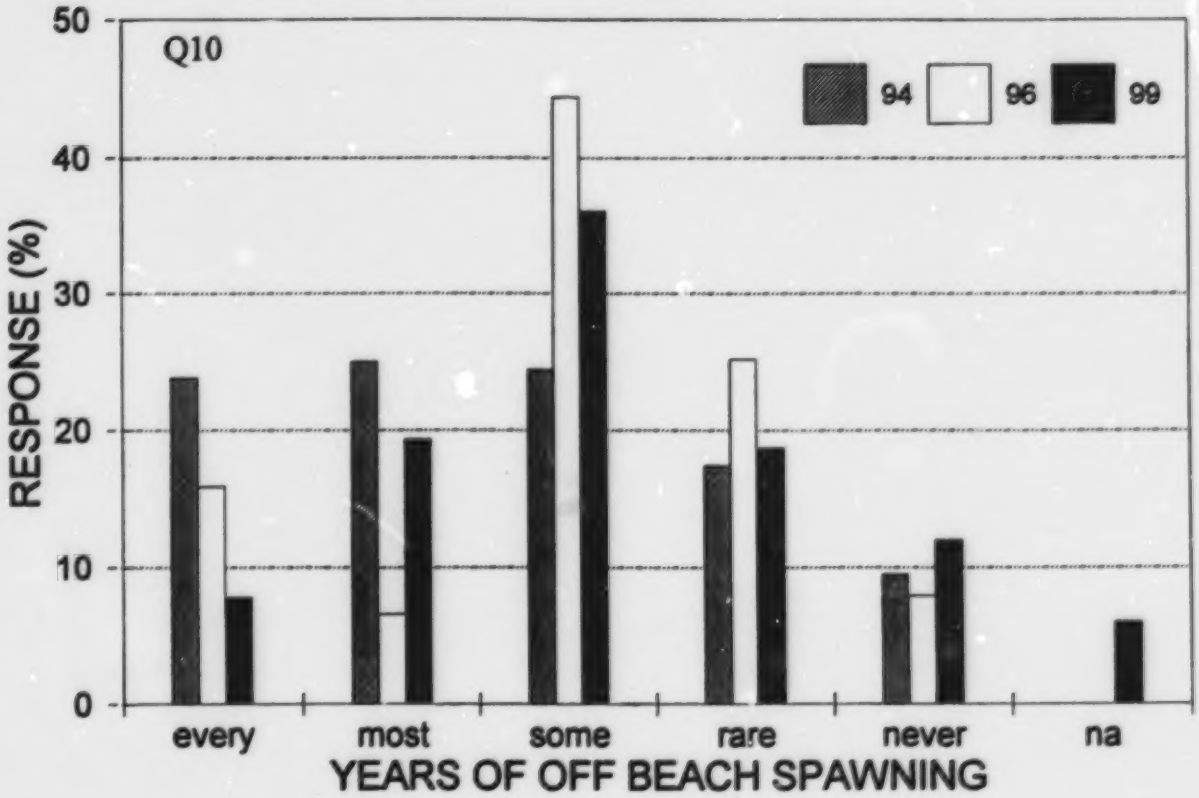

Fig. 9. The prevalence of off beach spawning reported in the 1994, 1996 and 1999 surveys. No answer given (na).

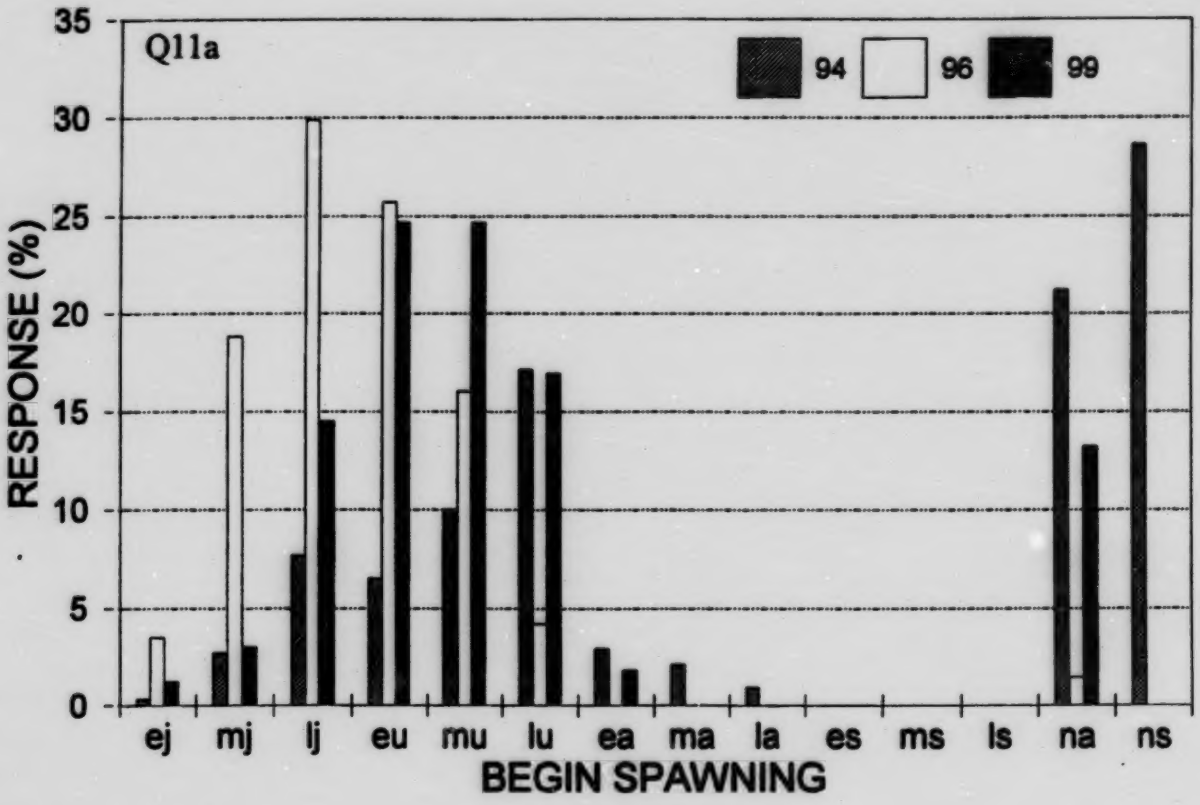

Fig. 10. The time when capelin began spawning in 1994 (Nakashima 1995), 1996 (Nakashima and Clark 1997) and 1999. Spawning times are early June=ej, mid June=mj, late June=lj, early July=eu, mid July=mu, late July=lu, early August=ea, mid August=ma, late August=la, early September=es, mid September=ms, and late September=ls. No answer given (na) and no spawning (ns) are shown.

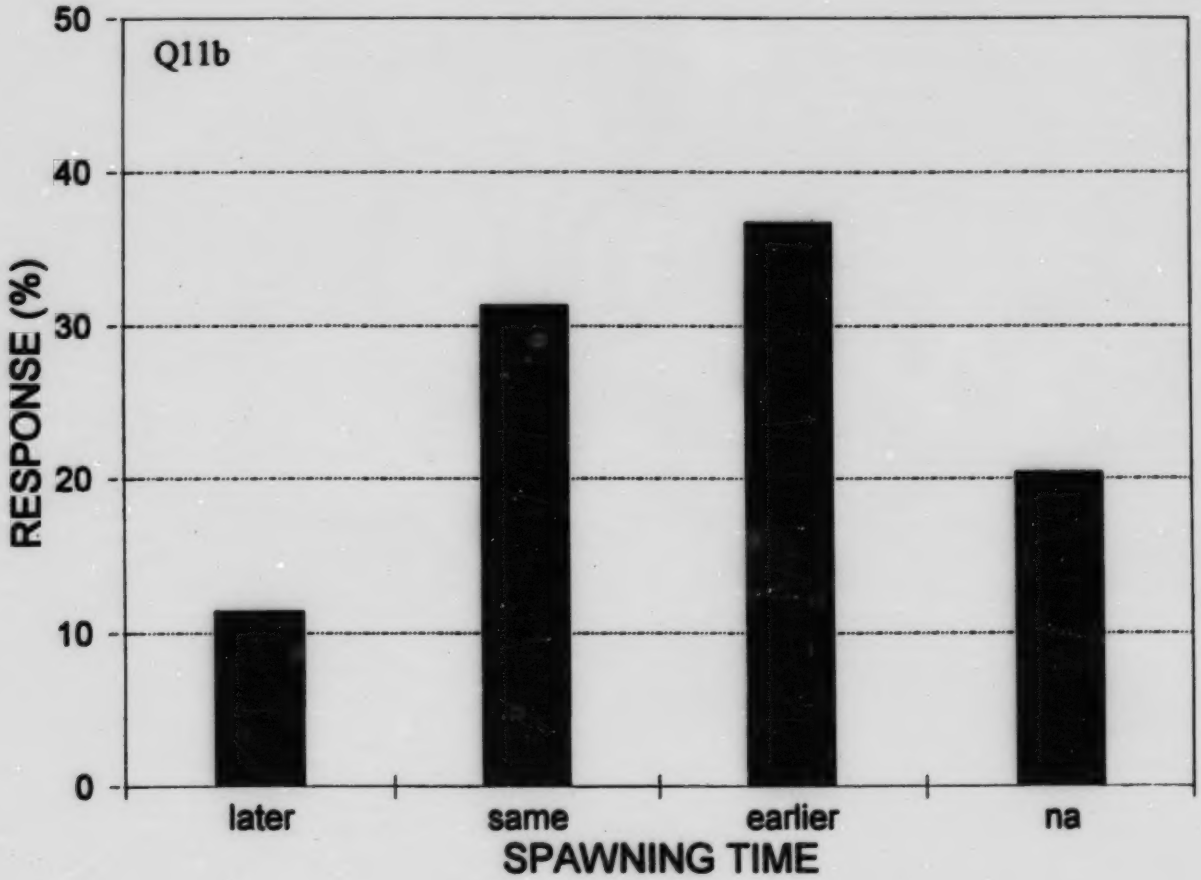

Fig. 11. The start of spawning in 1999 compared to 1998 in response to question 11b. No answer given (na).

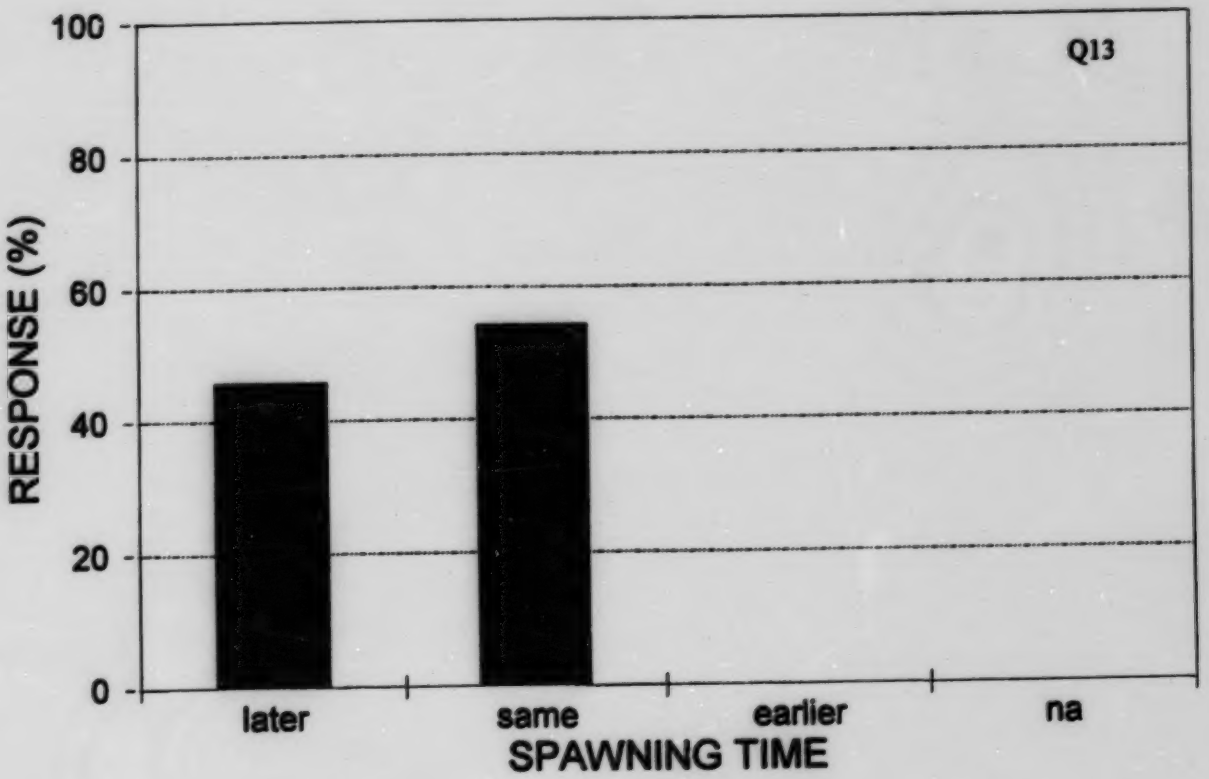

Fig. 12. Comparison of spawning times in 1999 to when respondents first fished capelin. No answer given (na).

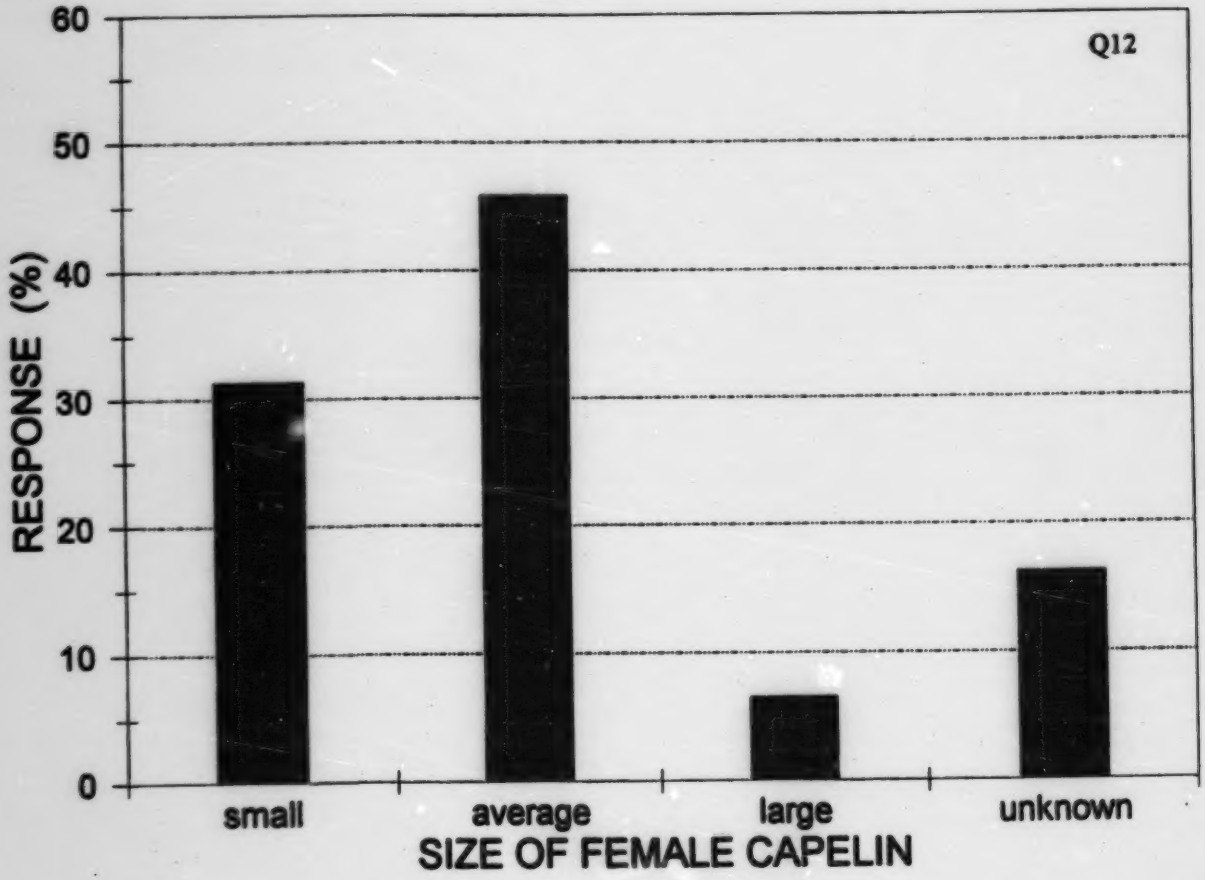

Fig. 13. Relative sizes of capelin.

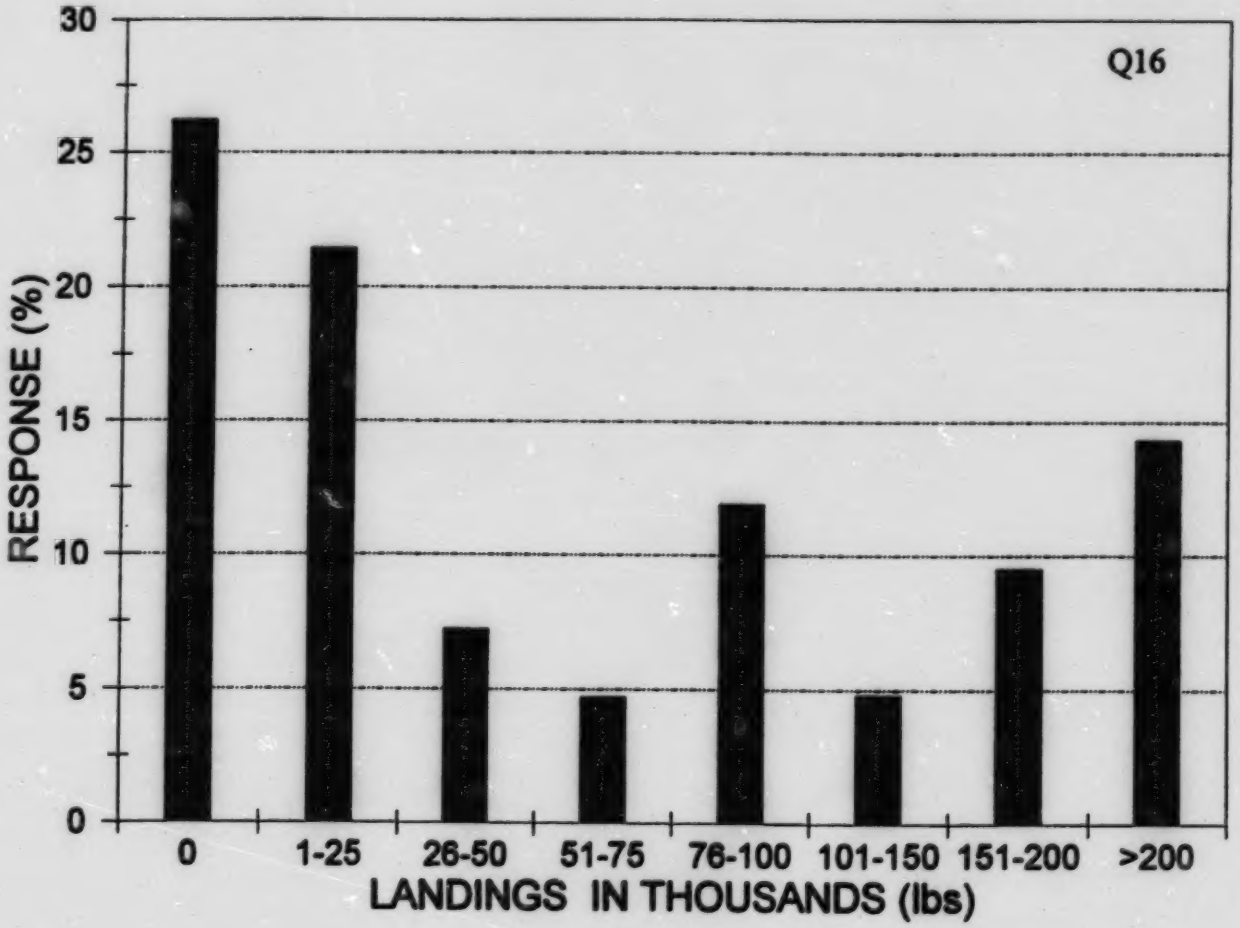

Fig. 14. Estimated capelin landings in 1999 by respondents to question 16.

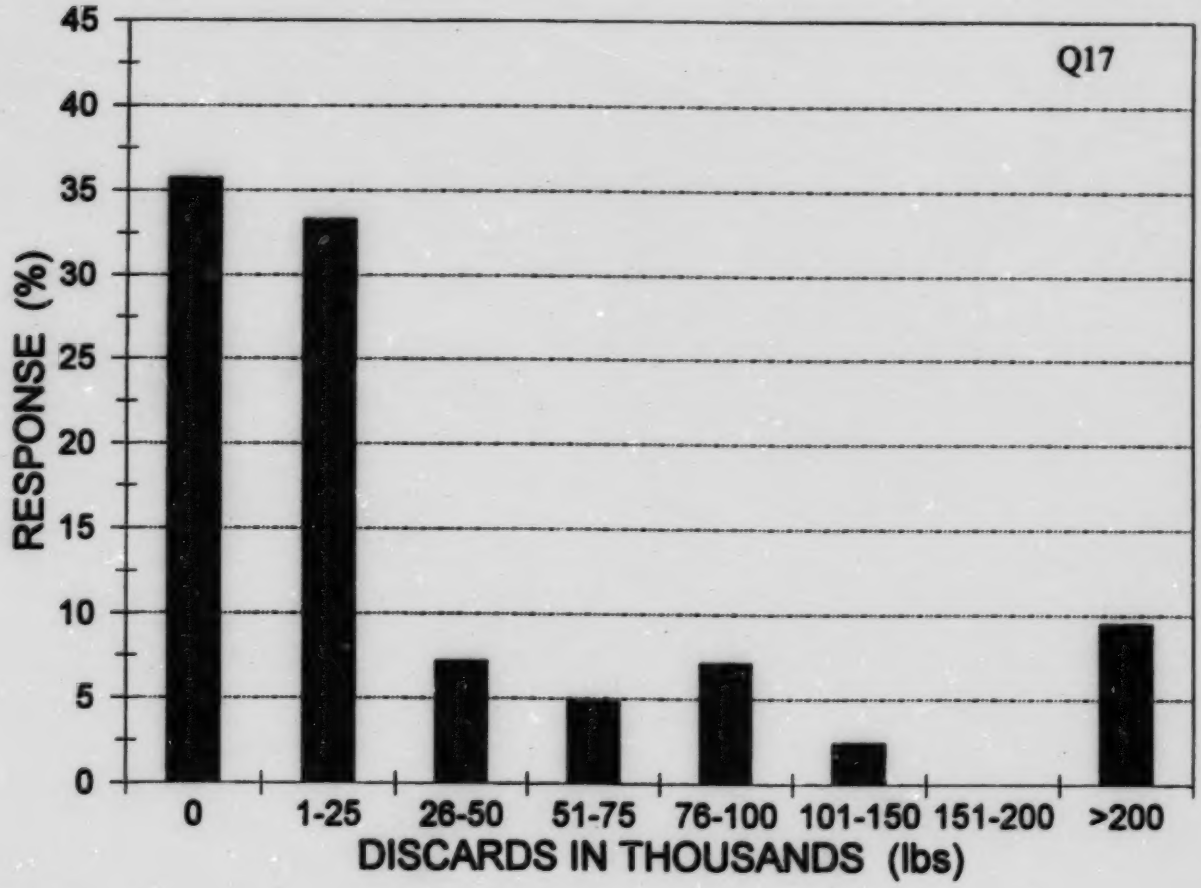

Fig. 15. Estimated discards in 1999 by respondents to question 17.

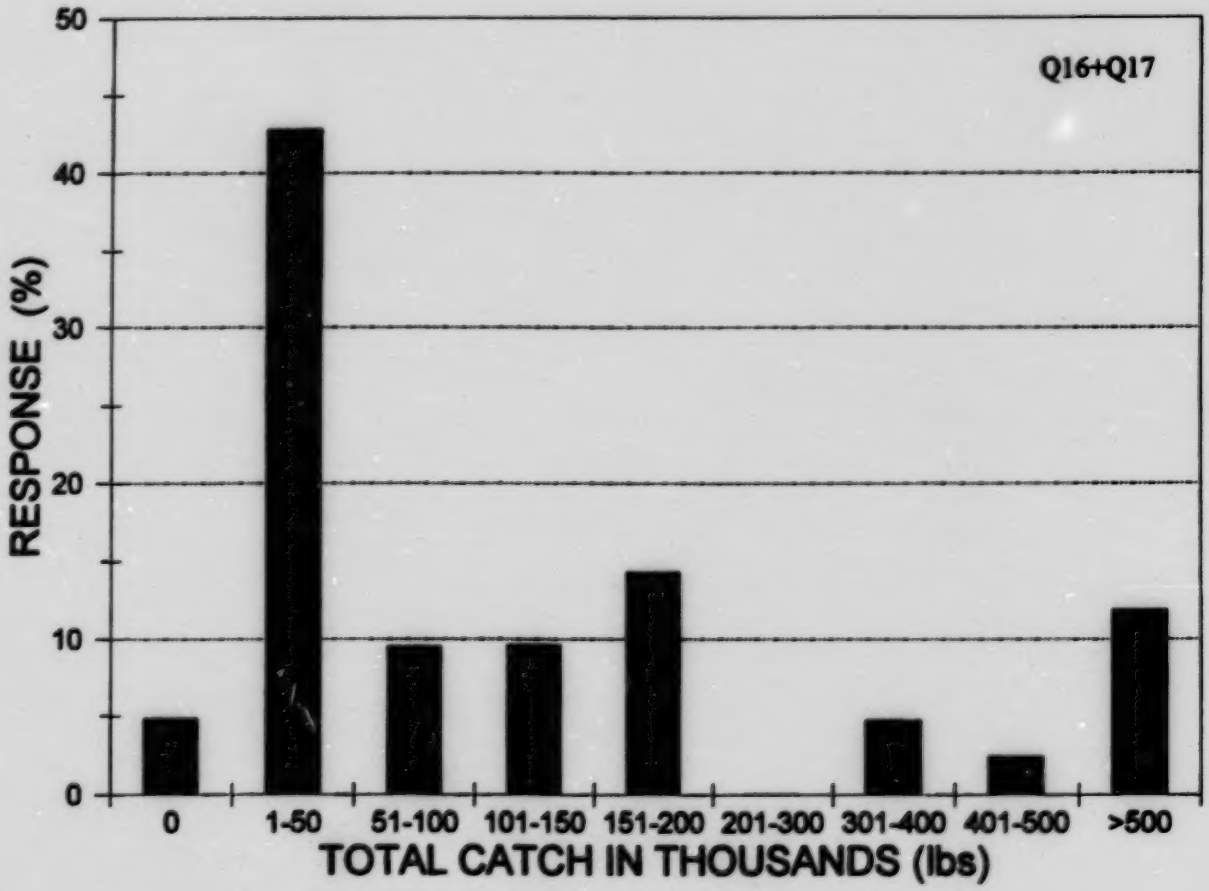

Fig. 16. Estimated total catch (discards + landings) in 1999.

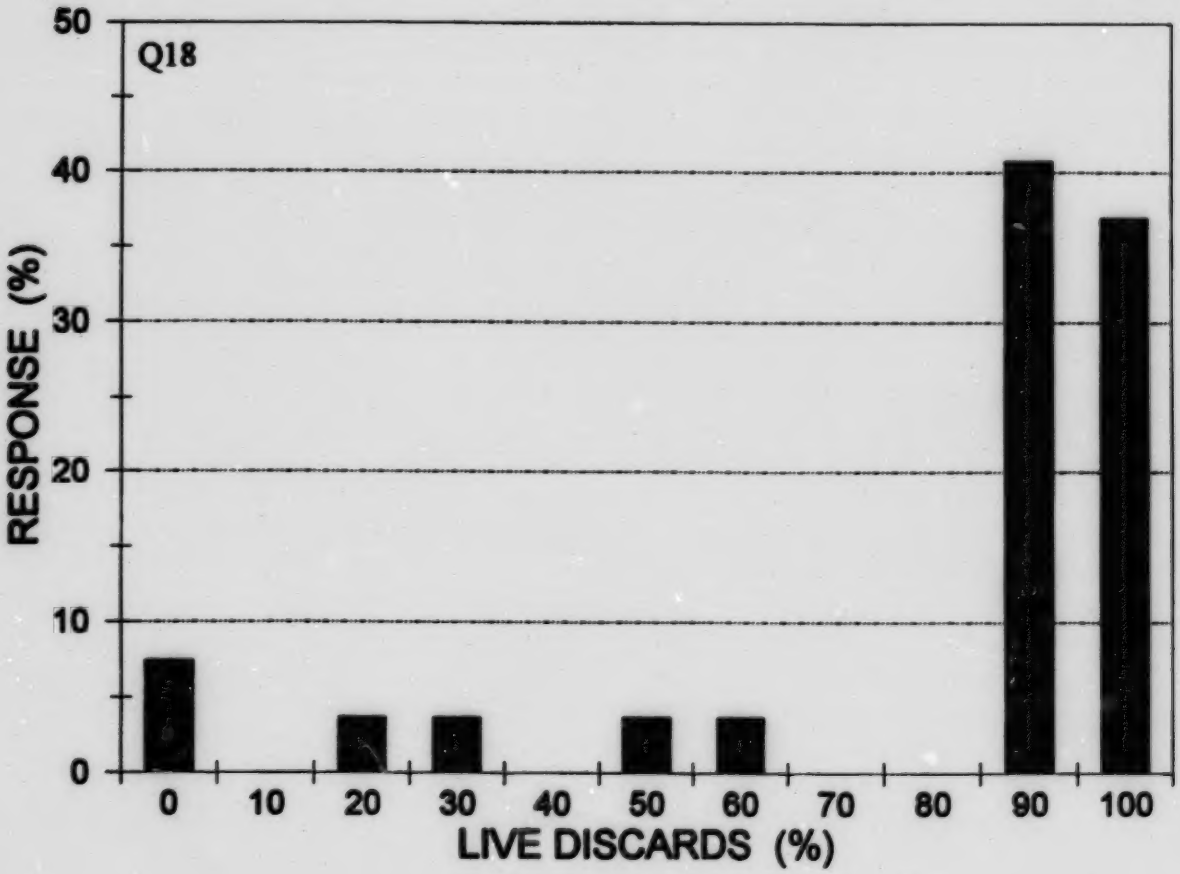

Fig. 17. Estimated survival of discarded capelin in 1999.

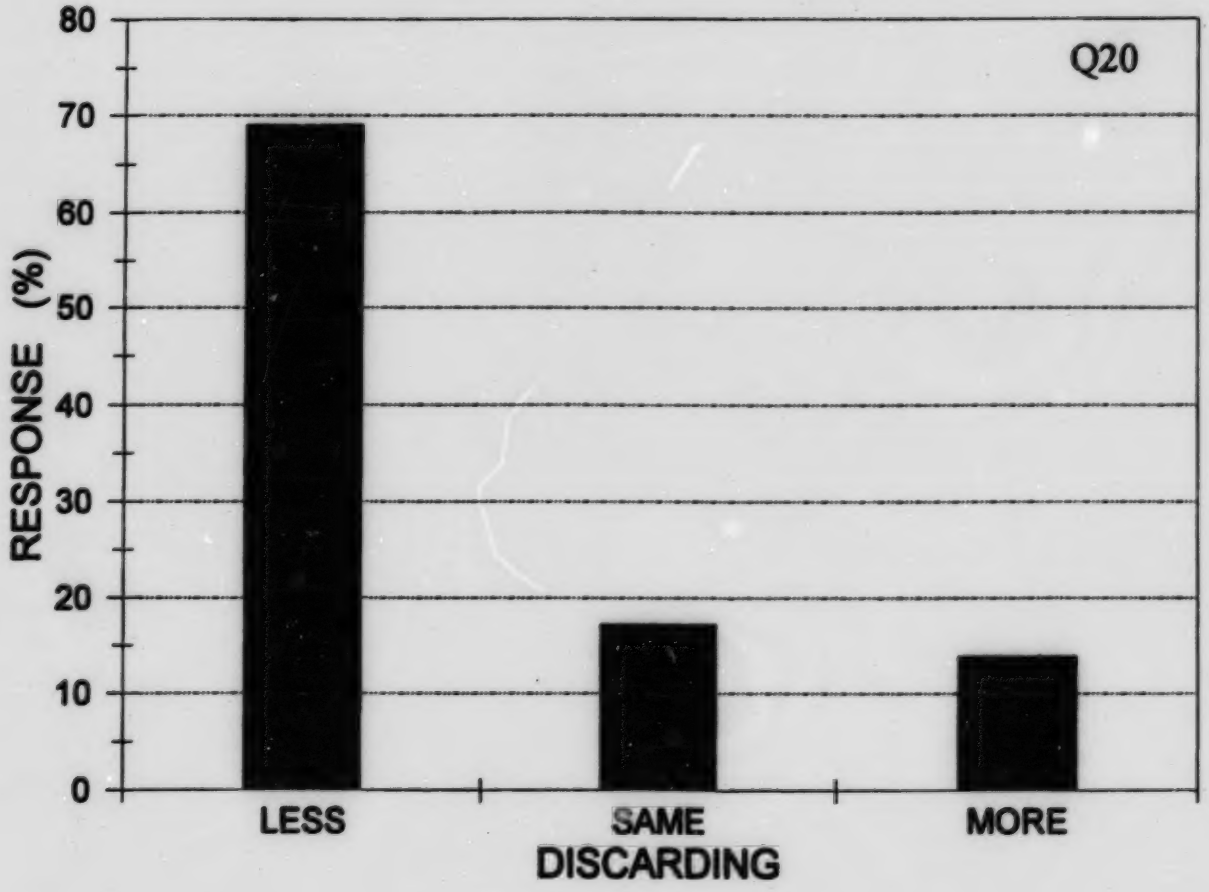

Fig. 18. Amount of discarding in 1999 compared to earlier years in response to question 20.

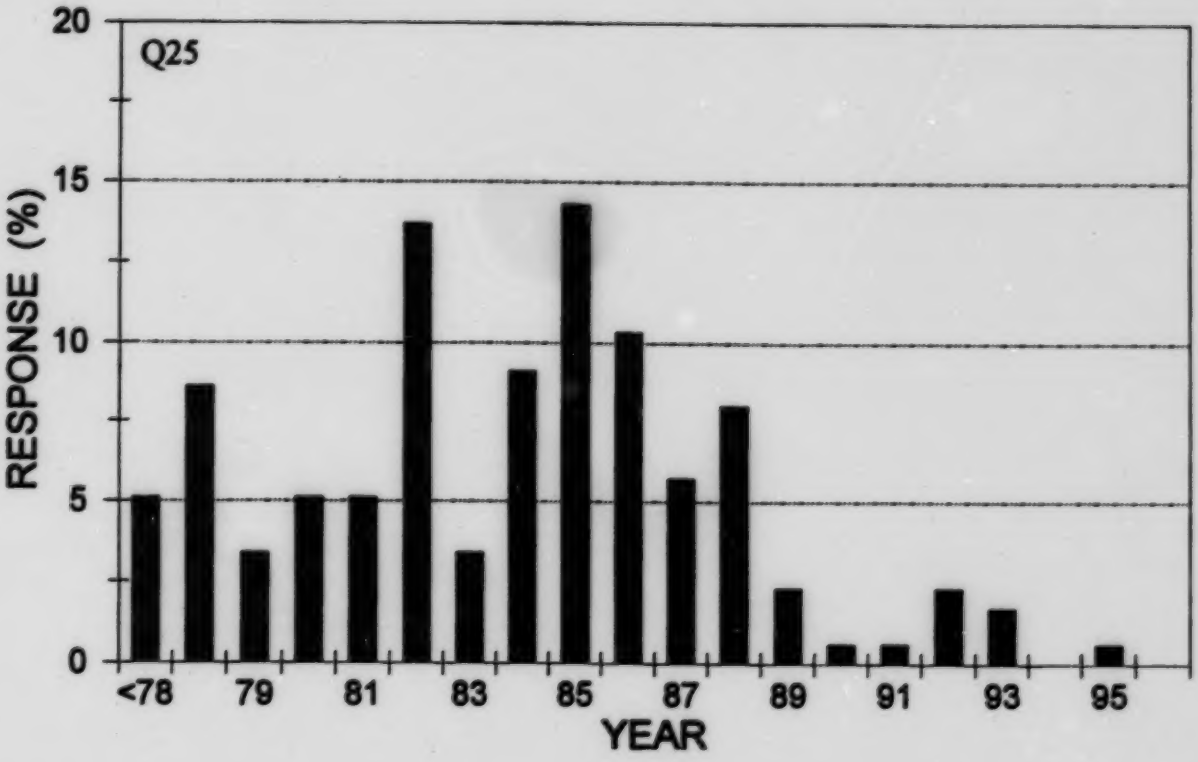

Fig. 19. Experience in the inshore capelin fishery.

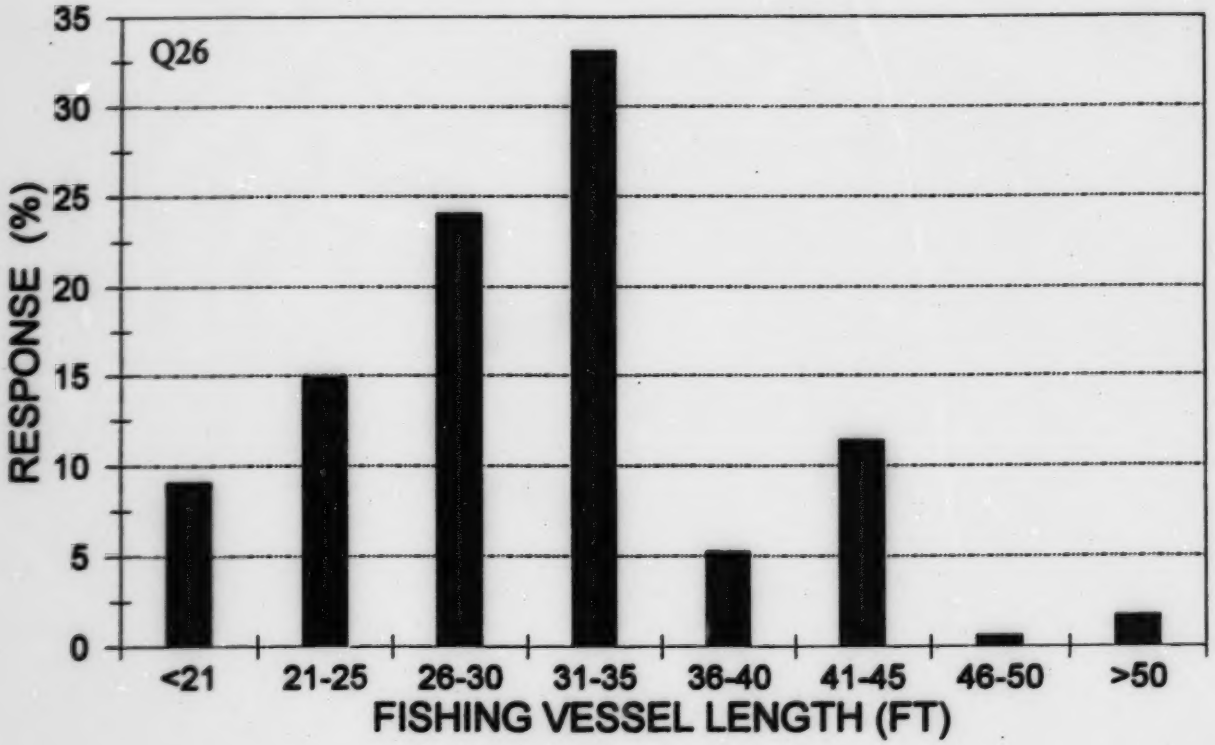

Fig. 20. Distribution of lengths of fishing vessels involved in the fixed gear fishery.

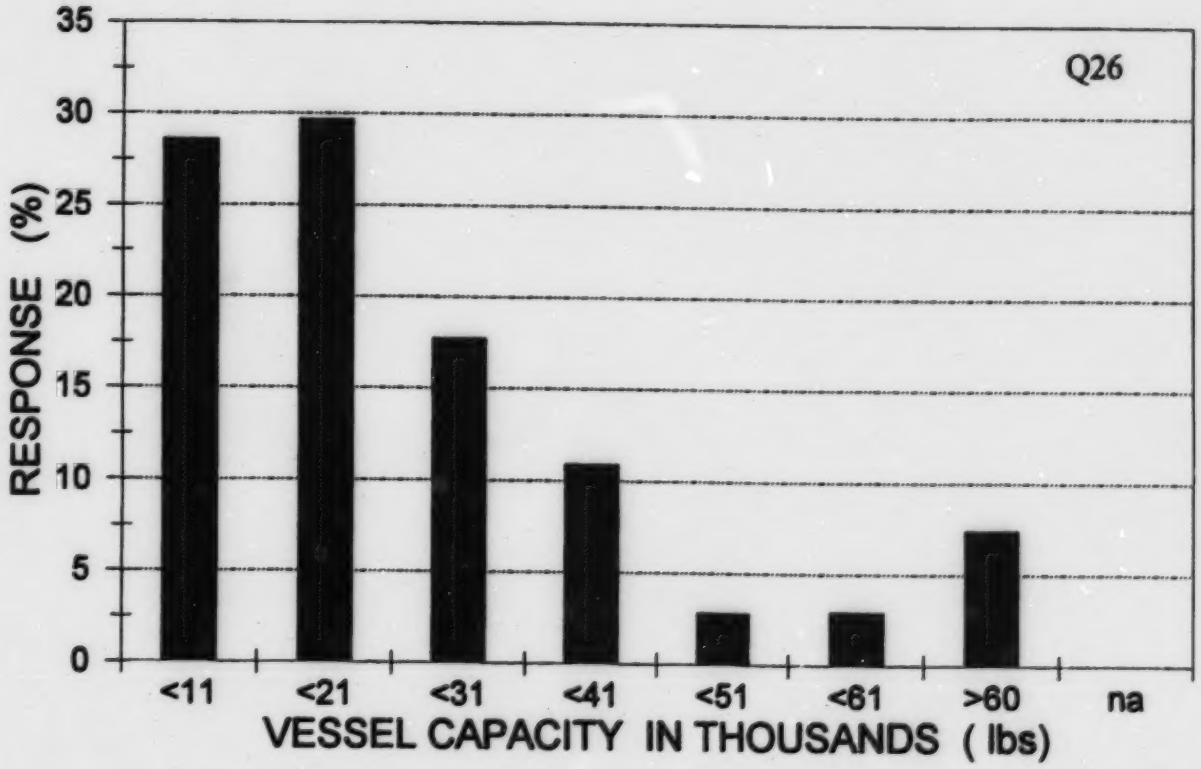

Fig. 21. Estimated fishing vessel capacity for capelin. No answer given (na).

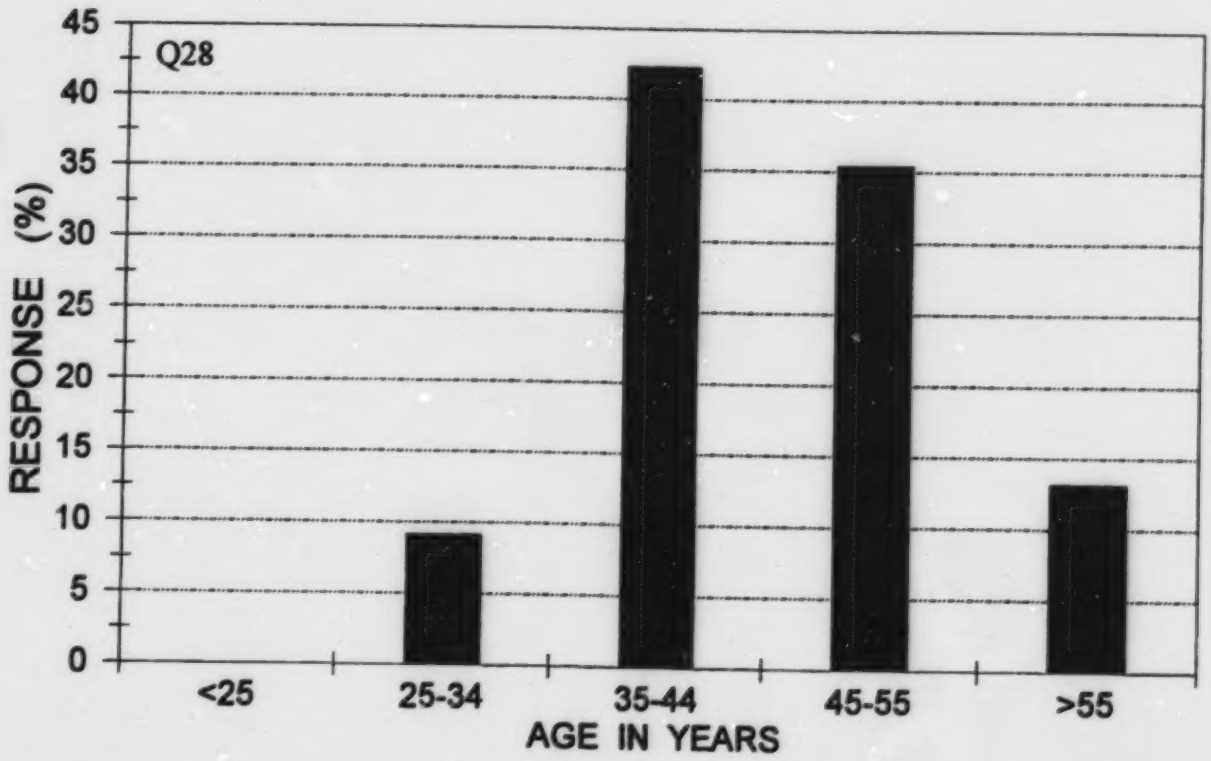

Fig. 22. Distribution of age of capelin fishers in 1999.

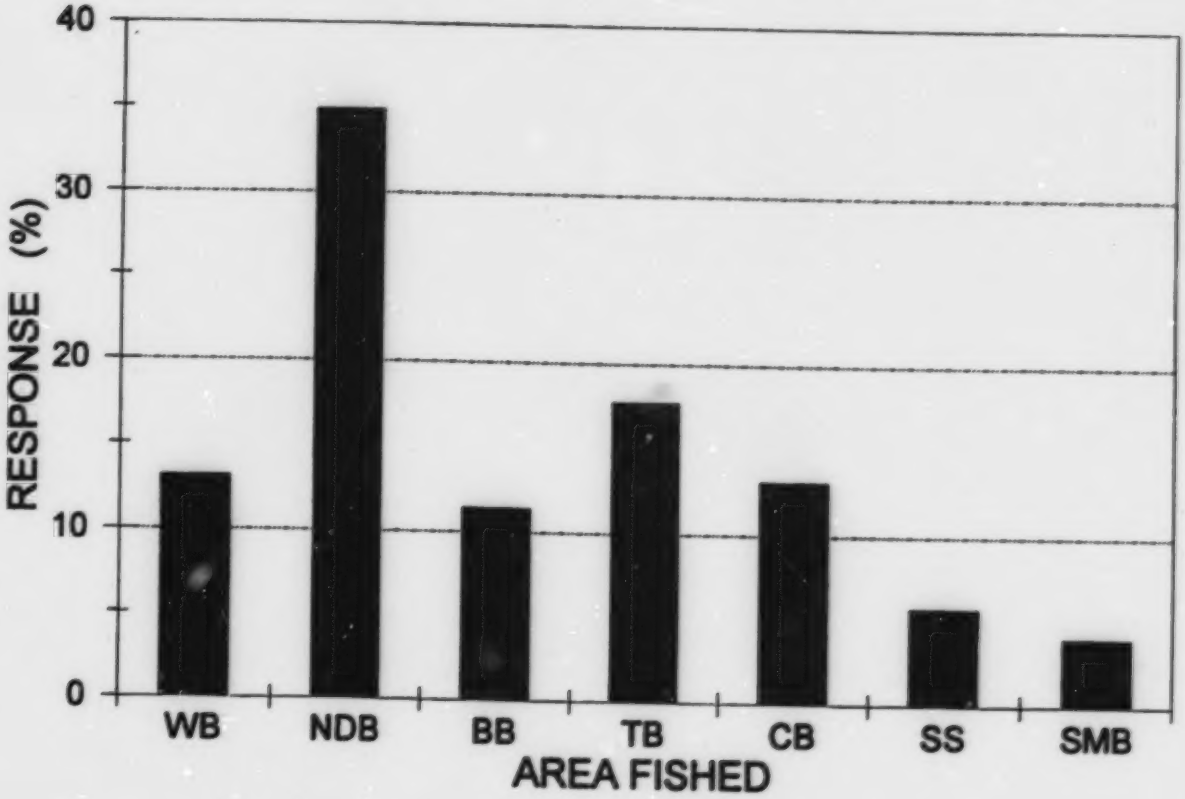

Fig. 23. Distribution of respondents among fishing areas (WB=White Bay, NDB=Notre Dame Bay, BB=Bonavista Bay, TB=Trinity Bay, CB=Conception Bay, SS=Southern Shore, SMB=Trepassey and St. Mary's Bay).

Appendix A

SURVEY QUESTIONNAIRE OF FIXED GEAR CAPELIN Licence HOLDERS

Questions on Abundance:

1. Using a scale of 1 to 10 with 1 being the lowest and 10 the highest how abundant (i.e. numbers of fish) were capelin in your area this year?

2. Using a scale of 1 to 10 with 1 being the lowest and 10 the highest how abundant (i.e. numbers of fish) were capelin in your area last year?

3. How would you describe the abundance of capelin this year compared to when you first started fishing capelin?

Questions on Spawning:

4. Approximately on how many beaches in your area do capelin usually spawn?

5. Approximately on how many beaches did capelin spawn this year?

   If 'none' or 'don't know' go to Ques. 8

6. How many beaches did capelin spawn on this year compared to last year?

7a. On a scale of 1 to 10 with 1 being low and 10 being high how intense was capelin spawning in your area this year?

7b. What was the intensity of capelin spawning this year compared to last year?

8. Did capelin spawn off beaches in your area in deeper water?

   If yes go to Ques. 9
   If 'no' or 'don't know' go to Ques. 10
   If no spawning on beaches or in deep water go to Ques. 14

9. Why do you think capelin spawned in deeper water this year?

10. How often since you started fishing have you observed capelin spawning off beaches in deeper water?

11a. When did capelin first spawn in your area this year?

11b. Did spawning start at the same time this year as last year?

12. What was the overall size of female capelin this year?

13. How does the timing of capelin spawning (beginning and end) this year compare to when you first started fishing capelin?

Questions on the Fishery.

14. Did you intend to fish for capelin this year?

If 'yes' continue, if 'no' go to Ques. 24

14b. Did you set your fishing gear or go out and search for capelin this year?

If 'yes' continue, if 'no' go to Ques. 24

15a. What type of fishing gear did you use?

If a 'trap' go to Ques. 15b if other gear types go to Ques. 15d

15b. How many traps did you fish?

15c. How much capelin does your trap(s) hold when full?

15d. Did you always fish this gear type or have you fished other types in the past?

If fished other gear types what were they?

16. Approximately how much capelin did you and your crew land this year?

17. Approximately how much capelin (live or dead) did you and your crew discard (i.e. did not land or sell)?

    If discarding >0 continue, if discarding is '0' go to Ques. 21

18. What percent of the discarded capelin do you think survived?

19. Why were capelin discarded? Please give reasons in order of importance.

20. How does the amount discarded this year compare to all the other years you've fished capelin?

21. While fishing capelin did you and your crew catch any other species (i.e. by catch)?

    If 'yes' continue, if 'no' go to Ques. 24

22. What species (three maximum) were they and approximately how many (weight) of each?

23. What was the condition of the by catch when released?

Questions on Climate/Ocean Conditions:

24. Weather plays an important role in the biology of capelin. Please describe the local weather and sea conditions in your area during capelin spawning season (usually June/July).

    Winds-force and direction, air temperature, sun or overcast, ice, water temperature

General Information:

25. In what year did you first start fishing capelin commercially?

26. What is the length and capacity (maximum weight of capelin it can carry) of your vessel?

27a. Have you always fished for capelin in the same location?

If 'no' continue, if 'yes' go to Ques. 28

27b. Where else have you fished for capelin?

28. How old are you?

The 1999 Inshore Capelin (Mallotus villosus) Fishery in NAFO Div. 3KL

by

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Introduction

Preliminary 1999 landings based on quota reports were 18,578 t (Table 1) in Div. 2J3KL compared to a quota allocation of 35,580 t (Appendix A). Fishing effort was low compared to previous years. Research logbooks were used to estimate catch and effort for mobile and fixed gear fisheries.

Materials and Methods

Capelin landings are normally extracted from Table M-18, Policy and Economics Branch, however purchase slips from the 1999 fishery are in the process of being keyed into the database. The reported landings are from the species Quota Report - 1999 for September 17, 1999 and are to be considered preliminary. Fixed gear landings have not been reconciled among gear types.

Commercial samples were collected by fishers and other reliable collectors. From each sample, length, sex, and maturity stage were measured on 200 fish and a stratified sample of 2 otoliths per sex per 1/2 cm length was taken for ageing.

Research logbooks were mailed to 42 purse seine and 147 fixed gear licensed fishers residing in Div. 3KL. In October staff visited many of the survey participants.

Results and Discussion

The Inshore Fishery

The inshore fishery in Div. 3KL is normally prosecuted by purse seines, capelin traps, and beach seines and has been regulated by quota management since 1982. Quotas by area and gear type established for 1999 are presented in Appendix A. The purse seine fishery opened in all areas on June 28, two days earlier than in 1998. It continued until the quota was caught, fish specifications failed to meet market criteria, or was officially closed on July 31 due to inactivity (Appendix B). The fixed gear fishery opened in many areas a few days after the purse seine fleet had found marketable capelin in the area. Fixed-gear fisheries did not open on the Southern Shore and in St. Mary's Bay in 1999. The reported landings for 1999 (Table 1) were almost half of what was landed in 1998 (Fig. 2, Table 1). In some areas 'tuck seines' were deployed when fishers observed that capelin stayed in deep water unavailable to traps and beach seines. These catches are coded as fixed gear.

Biological Sampling

In 1999, 50 commercial samples were processed throughout Div. 3KL (Table 2). The mean number of otolith pairs per sample was greater in Div. 3K than in Div. 3L (Table 2).

The 1999 spawning biomass in numbers was dominated by the 1996 year-class as three-year-olds followed by the 1997 year-class as two-year-olds (Table 3). These age compositions differ somewhat from those derived at Bellevue Beach (Nakashima and Slaney 2000).

Research Logbooks

Discounting those who did not fish in 1999, 42% of fixed gear and 67% of mobile gear fishers returned research logbooks (Table 4). Nine fished (two mobile and seven fixed gear) but did not send in a logbook. Two fixed gear fishers had no landings and did not fill in a logbook. Two fished with someone else and one lost their boat on the first day. There was a high proportion of those who did not fish in 1999. Two related factors mentioned in the logbooks and during the fall survey contributing to the low fishing effort were the low prices and lack of interest by

processors. Those who fished tended to have processors committed to buying their capelin. Some took the chance that someone would buy their catch. Also fisheries were open for cod and crab at the same time and many fishers chose to fish those species rather than participate in an uncertain capelin fishery.

Reported discarding was low in 1999. The reasons mentioned most often for discarding were low percentage of females, redfeed, and lack of sales (Table 5). In White Bay capelin were discarded from traps because females were spent (43%), redfeed levels were too high (26%), and plants were blocked (22%). In Notre Dame Bay low percentage of females was the problem (100%). In Bonavista Bay, redfeed (63%) was often reported as a problem. The 'miscellaneous' were catches where capelin were mixed with other species. In Trinity Bay difficulty selling capelin (53%) and low percentage of females (36%) were main problems encountered. Spent females (100%) were the reason for capelin were discarded from traps in Conception Bay. No quota was set for mobile gear on the Southern Shore. For the mobile fleet in White Bay, the one purse seiner reported no discards. In Notre Dame Bay redfeed (52%) and spent females (30%) were the main reasons purse seine catches were released. Discarding by seiners in Bonavista and Trinity Bays was due to redfeed (71% and 89% respectively). Small females (52%) and low percentage of females (40%) were important reasons for seiners in Conception Bay.

Discarding as a percentage of reported landings varied among areas for traps (Table 6: 10-90%) and for purse seines (Table 7: 0 to 27%). The overall discarding rate of 33% for traps was lower than in 1998 (Table 8) and the rate of 15% for purse seines was similar to 1998 and one of the lowest in the series (Table 9). The reported discards include 73 t given away by purse seiners to other vessels and 15 t given away by trap fishers. Excluding fish given away, according to the logbook reports 87% of trap and 94% of purse seine discards were released alive at sea. The dead discards reported in trap logbooks were due to blocked plants, inability to sell the catch, and spent females. The purse seine discards were discarded dead due to redfeed. In the present analysis (Tables 5-9), discards are defined as capelin caught but not landed by the fishers who caught them and includes capelin released alive and those dumped as dead fish.

Fishing effort for traps and for purse seines continue to increase from the low rates estimated in 1997. Traps averaged 7.0 fishing days and were hauled 12.3 times (Table 8). Purse seines searched for 9.7 days and averaged 25.5 sets (Table 9). Trap logbook data are from all areas between Conception Bay and White Bay with most of the activity occurring in Trinity Bay, (Table 6). Similarly, most of the purse seine logbook data were available from Trinity Bay (Table 7).

Catch/effort (CPUE) estimates were available since 1981 for traps and for purse seines (Tables 8 and 9). The 1999 trap CPUE of 5.3 t/day was lower than in 1998 and lower than the series (1981-1998) average of 6.1. The estimate of 3.0 t/haul was slightly less than the series average of 3.4. The 1999 purse seine CPUE of 31.3 t/day was one of the highest in the series and the CPUE of 11.9 t/set was higher than the series (1981-1998) average of 10.1.

Conclusions

Discarding varied among areas and gear types. Discarding was 33% from traps and 15% from purse seines which indicated low rates of discarding. Most were reported as released live at sea. The main reasons for releasing capelin were low percentage of females, redfeed, and problems selling the catch, especially with blocked plants. Boat quotas were an important consideration for purse seiners. Problems with spent females in some areas suggest that spawning had already started before these areas were opened. The 1999 trap CPUE is similar to 1998 in the C/D series. The purse seine C/S was among the higher ones in its C/S series and the trap C/H was one of the lower ones in the C/H series. When staff were meeting with logbook participants in the fall many fishers reported that capelin stayed off in deeper water and were unavailable to capelin traps, similar to comments raised the last two years. As in 1998, in some areas fishers used 'tuck' seines to fish capelin.

We continue to suggest that fishing in recent years is very different than in the 1980s. Fishing effort has increased from 1997, however trap and purse seine effort still remains low (Fig. 3, 4). Trap fishing days and purse seine searching time is low in the 1990s primarily due to monitoring initiatives put in place to reduce discarding of

unmarketable capelin. The effect on fishing effort has been to concentrate the effort only when capelin are highly available and to reduce fishing time dramatically. In 1999 monitoring was not used for many areas and fisheries. The lack of interest by many licence holders mainly because of low prices and lack of interest by processors resulted in a significant reduction in effort in 1999. Because of these influences on effort fishing effort, the catch rate data in recent years have not been considered as reliable indicators of stock abundance (Nakashima and Evans 1999).

Acknowledgments

The continuing support of those who have participated in the research logbook program has provided valuable insights about the fishery and fishing. The inshore commercial sampling program was organized by P. J. Williams, otoliths were aged by P. G. Eustace, and M. Y. Farrell assisted in the preparation of the manuscript.

References

Nakashima, B. S. and G. T. Evans. 1999. Yearclass strength of capelin (Mallotus villosus) using a weighted multiplicative model. pp. 168-181. In: Anon. Capelin in SA2 + Div. 3KL. CSAS DFO Atl. Fish. Res. Doc. 99/206.

Nakashima, B. S. and B. W. Slaney. 2000. Spawning and early development of capelin (Mallotus villosus) at Bellevue Beach, Trinity Bay in 1999. pp. . In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 00/.

Table 1. Inshore capelin landings (t) by fishing gear (vessels <21 m in length) by area (White Bay = WB, Notre Dame Bay = NDB, Bonavista Bay = BB, Trinity Bay = TB, Conception Bay = CB, Southern Shore = SS, St. Mary's and Trepassey Bays = SMB) and by NAFO Division.

Year	Div.	Area	Purse seine	Beach seine	Trap	Dipnet	Total	
1992	**2J**		**0**	**0**	**0**		**0**	
		WB	2995	126	7602		10723	
		NDB	2819	1113	1695		5627	
	3K		**5814**	**1239**	**9297**		**16350**	
		BB	977	28	60		1065	
		TB	69	26	53		148	
		CB	411	57	160		628	
		SS	0	5	21		26	
		SMB	25	3	26		54	
	3L		**1482**	**119**	**320**		**1921**	
1993	**2J**		**0**	**1**	**0**		**1**	
		WB	1583	197	5108		6888	
		NDB	1447	2503	2323		6273	
	3K		**3030**	**2700**	**7431**		**13161**	
		BB	1734	92	1920		3746	
		TB	1989	365	4568		6922	
		CB	4712	50	3377		8139	
		SS	57	31	1480		1568	
		SMB	2102	4	404		2510	
	3L		**10594**	**542**	**11749**		**22885**	
1994	**2J**		**0**	**0**	**0**		**0**	
		WB	0	20	0		20	
		NDB	23	23	1		47	
	3K		**23**	**43**	**1**		**67**	
		BB	0	2	0		2	
		TB	23	54	4		81	
		CB	0	4	10		14	
		SS	0	16	722		738	
		SMB	0	3	55		58	
	3L		**23**	**79**	**791**		**893**	
1995	**2J**		**0**	**0**	**0**	**0**	**0**	
		WB	0	2	0	0	2	
		NDB	0	25	1	2	28	
	3K		**0**	**27**	**1**	**2**	**30**	
		BB	0	35	0	5	40	
		TB	0	16	1	4	21	
		CB	0	19	2	1	22	
		SS	0	9	0	0	9	
		SMB	0	6	0	0	6	
	3L		**0**	**85**	**3**	**10**	**98**	
1996	**2J**		**15**	**0**	**7**	**0**	**22**	
		WB	1278	1	3462	0	4741	
		NDB	1258	1121	1772	0	4151	
	3K		**2551**	**1122**	**5241**	**0**	**8914**	
		BB	1204	9	1942	0	3155	
		TB	1906	31	2934	1	4872	
		CB	3242	14	3774	0	7030	
		SS	8	0	90	0	98	
		SMB	1129	16	535	0	1680	
	3L		**7489**	**70**	**9275**	**1**	**16835**	

Table 1. Continued ...

Year	Div.	Area	Purse seine	Beach seine	Trap	Dipnet	Total
1997[1]	2J		14	0	0		14
		WB	2964	139	3178		6281
		NDB	1558	886	508		2952
	3K		4522	1025	3686		9233
		BB	463	0	0		463
		TB	468	8	4		480
		CB	639	0	0		639
		SS	17	0	127		144
		SMB	1832	0	3		1835
	3L		3419	8	134		3561
1998[1]	2J		0	0	428		428
		WB	3508	50	4416		7974
		NDB	716	1294	962		2972
	3K		4224	1344	5378		10946
		BB	1585	303	1173		3061
		TB	2264	40	2264		4568
		CB	3571	0	4428		7999
		SS	140	0	402		542
		SMB	1784	0	468		2252
	3L		9344	343	8735		18422
1999[1,2]	2J		0		0		0
		WB	1156		2675		3831
		NDB	2414		1214		3628
	3K		3570		3889		7459
				BB 1518	738	2256	
		TB	2332		2725		5057
		CB	3367		439		3806
		SS	0		0		0
		SMB	0		0		0
	3L		7217		3902		11119

[1] provisional
[2] trap landings include beach seine landings

Table 2. Summary of inshore commecial samples processed and aged from 1999 in Div. 3KL.

Gear type	No. of samples LSM	Strat.	No. of otoliths aged (N)	Mean no. otoliths ± SD Per sample
Div. 3K	8	8	275	34.4 ± 4.6
Purse seine	6	5	179	35.8 ± 1.6
Capelin trap	5	4	132	33.0 ± 2.9
Beach seine				
Total	19	17	576	
Div. 3L	15	15	493	32.9 ± 2.1
Purse seine	12	12	412	34.3 ± 2.1
Capelin trap	4	3	94	31.3 ± 2.1
Beach seine				
Total	31	30	999	

Table 3. Age compositions (%) of capelin from the inshore commercial capelin fishery, Div. 3KL.

Sex / Year	Age 2	3	4	5	6
Males					
1982	+	90.5	8.7	0.7	+
1983	0.3	60.8	38.5	0.3	0
1984	0.3	36.0	62.9	0.8	0
1985	4.9	65.4	27.9	1.7	+
1986	0.2	56.7	42.5	0.5	0
1987	0.2	11.4	86.8	1.5	0
1988	3.7	70.2	23.1	3.0	0
1989	0.3	76.8	22.8	0.1	0
1990	0.4	33.6	65.7	0.2	0
1991	9.2	47.8	41.6	1.4	+
1992	7.9	81.4	10.5	0.2	0
1993	5.9	88.4	5.6	0.1	0
1994[a]	23.8	56.7	19.5	0	0
1995[b]	34.7	63.4	1.9	0	0
1996	25.0	73.4	1.5	0	0
1997	58.7	34.1	7.1	0	0
1998	33.9	60.0	3.5	0	0
1999	32.3	65.9	1.6	0.2	0
Females					
1982	1.5	77.9	12.4	6.4	1.8
1983	5.8	58.8	33.4	2.0	+
1984	2.6	41.0	48.0	8.1	0.3
1985	13.4	57.3	18.5	10.3	0.5
1986	0.2	65.5	29.5	3.7	1.1
1987	4.8	19.1	67.1	8.5	0.4
1988	11.6	51.8	12.1	23.0	1.5
1989	1.3	70.7	23.4	2.0	2.6
1990	1.4	44.1	51.9	2.5	+
1991	12.6	49.5	29.4	8.4	0.1
1992	17.6	67.8	12.9	1.7	+
1993	10.4	82.1	7.3	0.2	+
1994[a]	33.4	43.1	19.7	3.8	0
1995[b]	55.8	37.3	6.4	0.4	0.1
1996	33.3	58.1	8.5	0.2	0
1997	47.7	22.5	25.1	4.7	0
1998	48.3	39.3	8.0	1.4	0
1999	46.2	45.7	7.8	0.4	0
Sexes Combined					
1982	0.7	84.6	10.5	3.4	0.8
1983	3.3	59.7	35.7	1.3	+
1984	1.5	38.6	55.2	4.5	0.2
1985	10.1	60.4	22.1	7.0	0.4
1986	0.2	62.1	34.5	2.5	0.7
1987	2.9	15.9	75.5	5.5	0.2
1988	8.4	59.1	16.5	15.1	0.9
1989	0.8	73.5	23.1	1.2	1.4
1990	1.0	39.7	57.8	1.5	+
1991	11.1	48.8	34.5	5.5	0.1
1992	13.3	73.9	11.8	1.0	+
1993	8.5	84.8	6.6	0.1	+
1994[a]	31.1	46.3	19.7	2.9	0
1995[b]	43.7	52.3	3.8	0.2	0
1996	29.9	64.4	5.6	0.1	0
1997	52.2	27.3	17.8	0.8	0
1998	42.0	48.3	6.0	0.8	0
1999	41.2	53.0	5.5	0.3	0

a - low sample numbers (N = 11) and from a small area
b - research samples only

Table 4. The distribution of research logbooks in 2000.

NAFO Div.	Gear type	No. of fishers	No. returned	No. never fished	No logbook
3K	Fixed	53	8	37	8
3L	Fixed	89	20	57	12[a]

a - 1 returned letter but insufficient information to code
- 1 fished, no landings, no log kept

Table 5. Percent contribution by weight of reasons for discarding capelin in 1999. This analysis excludes capelin given to other fishers.

Area	Redfeed	Low % females	Small females	Males picked out	Females spawned out	Boat quota/ no sales	Misc.	Not Given
Traps:								
White Bay	26	0	0	0	43	22	9	0
Notre Dame Bay	0	100	0	0	0	0	0	0
Bonavista Bay	63	0	0	0	0	0	37	0
Trinity Bay	1	36	0	0	0	53	10	0
Conception Bay	0	0	0	0	100	0	0	0
Purse seine:								
White Bay	0	0	0	0	0	0	0	0
Notre Dame Bay	52	0	0	0	30	12	6	0
Bonavista Bay	71	0	0	0	0	29	0	0
Trinity Bay	89	11	0	0	0	0	0	0
Conception Bay	0	40	53	0	0	7	0	0

Table 6. Capelin landings (t), discards (t), and catch/effort from research logbook records for capelin traps in Div. 3KL in 1999.

Area	No. fishers	No. traps	Landings	Discard logbook	Bycatch		No. days fished (D)	No. times hauled (H)	C = Landings + discards	
					Cod	Herring			C/D	C/H
White Bay	6	7	275.5	27.4	0.1	0.1	35.6	53	8.5	5.7
Notre Dame Bay	1	1	14.1	12.9	+	0	3.2	8	8.4	3.4
Bonavista Bay	3	3	60.7	4.2	2	2.7	16.7	32	3.9	2.0
Trinity Bay	9	12	306.7	169.8	1.5	0.1	110.9	198	4.3	2.4
Conception Bay	1	1	13.7	5.0	0	0	1.8	4	10.4	4.7

Table 7. Capelin landings (t), discards (t), bycatch (t), and catch/effort compiled from research logbooks for purse seines in Div. 3KL in 1999.

Area	No. of fishers	Landings By logbook	Discards by logbook*	No. days fished	No. sets made	C = landings + discards	
						C/D	C/S
White Bay	1	153.6	0	11	20	14.0	7.7
Notre Dame Bay	6	477.3	93.0	18	42	31.7	13.6
Bonavista Bay	6	473.4	49.9	13	30	40.3	17.4
Trinity Bay	8	750.7	200.3	28	89	34.0	10.7
Conception Bay	7	786.0	54.9	27	74	31.1	11.4

* includes capelin given to other fishers

Table 8. Capelin landings (t), discards (t), bycatch (t), and catch/effort from research logbook records for capelin traps in Div. 3KL, 1981-93, 1996-99. Data available from Div. 3L only for 1981 and 1982.

Year	No. Fishers	No. traps	Landings	Discard Logbook	Bycatch		No. days fished (D)	No. Times Hauled (H)	C = Landings + discards	
					Cod	Herring			C/D	C/H
1981	35	41	1281.0	417.7	6.4	0	577	680	2.9	2.5
1982	60	81	4366.5	605.2	58.5	0	1630	1996	3.1	2.5
1983	50	71	3051.2	1338.0	30.1	38.5	1277	1460	3.4	3.0
1984	67	89	4172.5	634.1	45.1	0.4	1615	2442	3.0	2.0
1985	60	80	3011.3	1850.1	34.2	0.2	1108	1508	4.4	3.2
1986	64	91	5056.4	1436.4	18.0	0.5	1567	2095	4.8	3.6
1987	68	93	3150.6	2437.5	11.5	+	622	1104	9.0	5.1
1988	86	125	6792.6	1500.4	35.9	1.1	1353	2415	6.1	3.4
1989	102	154	6275.8	2188.1	55.5	0.2	1314	2431	6.4	3.5
1990	106	167	5538.1	2986.6	10.7	1.9	1041	1825	9.2	5.3
1991	59	76	2793.0	1187.5	16.7	1.5	860	1325	5.9	3.8
1992	28	34	1225.8	567.1	1.5	5.7	297	666	6.0	2.7
1993	59	78	2261.1	297.0	20.7	37.0	400	863	6.4	3.0
1996	52	68	1719.4	930.8	79.2	3.6	274	692	9.7	3.8
1997	17	22	516.3	384.7	5.5	6.6	84	198	10.7	4.6
1998	51	73	1548.6	903.1	24.5	34.4	394	840	6.2	2.9
1999	20	24	670.7	219.3	3.6+	2.9+	168	295	5.3	3.0

Table 9. Capelin landings (t), discards (t), and catch/effort from research logbook records for purse seines in Div. 3KL, 1981-93, 1996-99.

Year	No. fishers	Landings	Discards logbook	No. days fished (D)	No. sets Made (S)	C = landings + discards	
						C/D	C/S
1981	23	2705.3	810.4	376	707	9.4	5.0
1982	61	11541.9	2484.8	859	1670	16.3	8.4
1983	48	6439.0	4551.3	626	1155	17.6	9.5
1984	46	8185.5	1517.2	679	1305	14.3	7.4
1985	35	4191.0	2314.3	396	696	16.4	9.3
1986	36	8654.5	2745.2	605	991	18.8	11.5
1987	29	2100.5	869.1	169	267	17.6	11.1
1988	41	8282.7	1247.1	476	927	20.0	10.3
1989	46	7463.5	1687.1	421	863	21.7	10.6
1990	32	5081.4	2327.4	344	630	21.5	11.8
1991	9	699.0	413.7	74	95	15.0	11.7
1992	17	1719.8	254.0	95	146	20.8	13.5
1993	21	2448.7	291.5	169	292	16.2	9.4
1996	23	1327.9	396.6	101	181	17.1	9.5
1997	27	1489.8	648.7	91	192	23.5	11.1
1998	26	2533.5	300.9	135	247	21.0	11.5
1999	10	2641.0	398.1	97	255	31.3	11.9

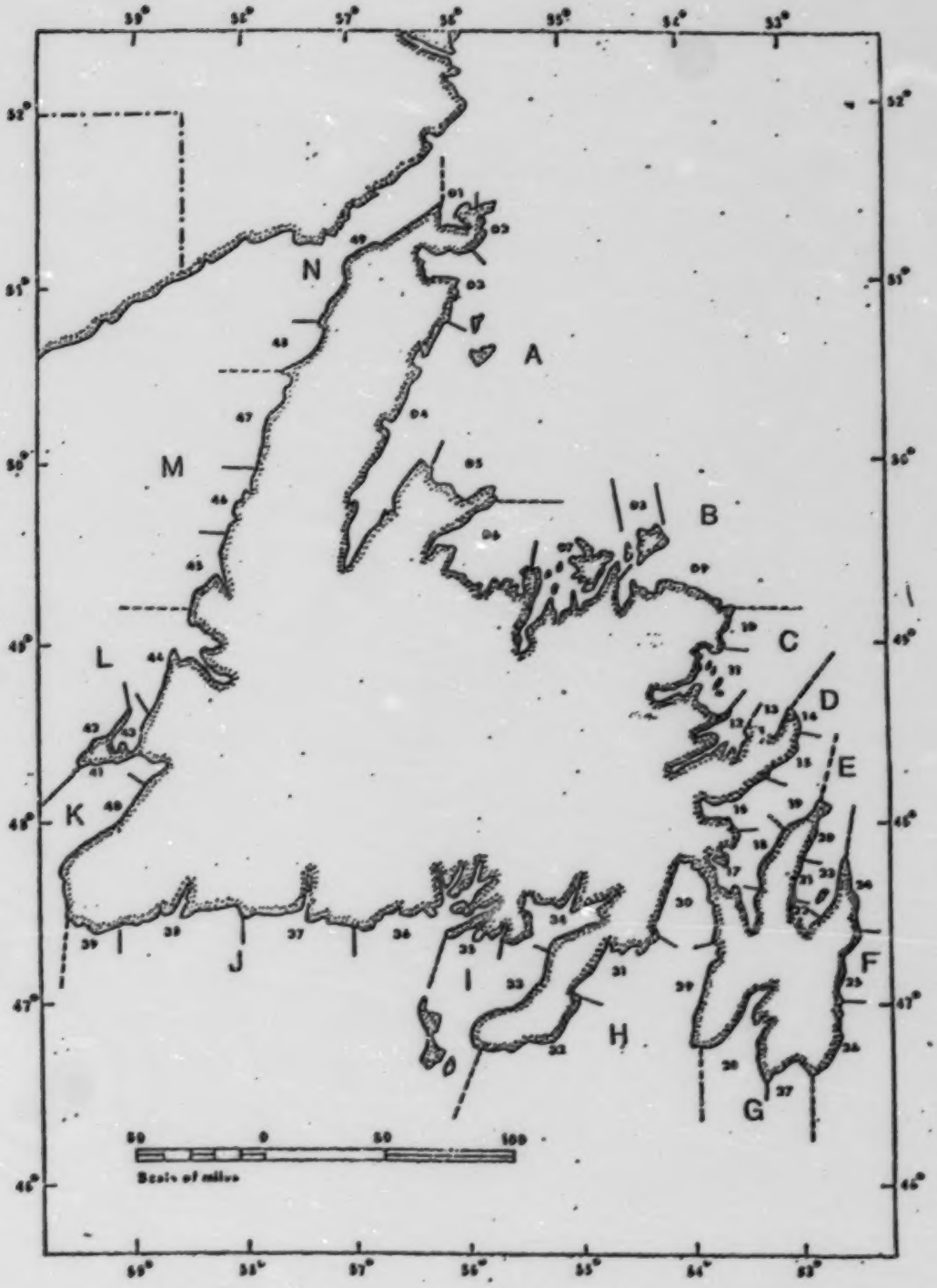


Fig. 1. Statistical areas and statistical sections (numeric) for Newfoundland.

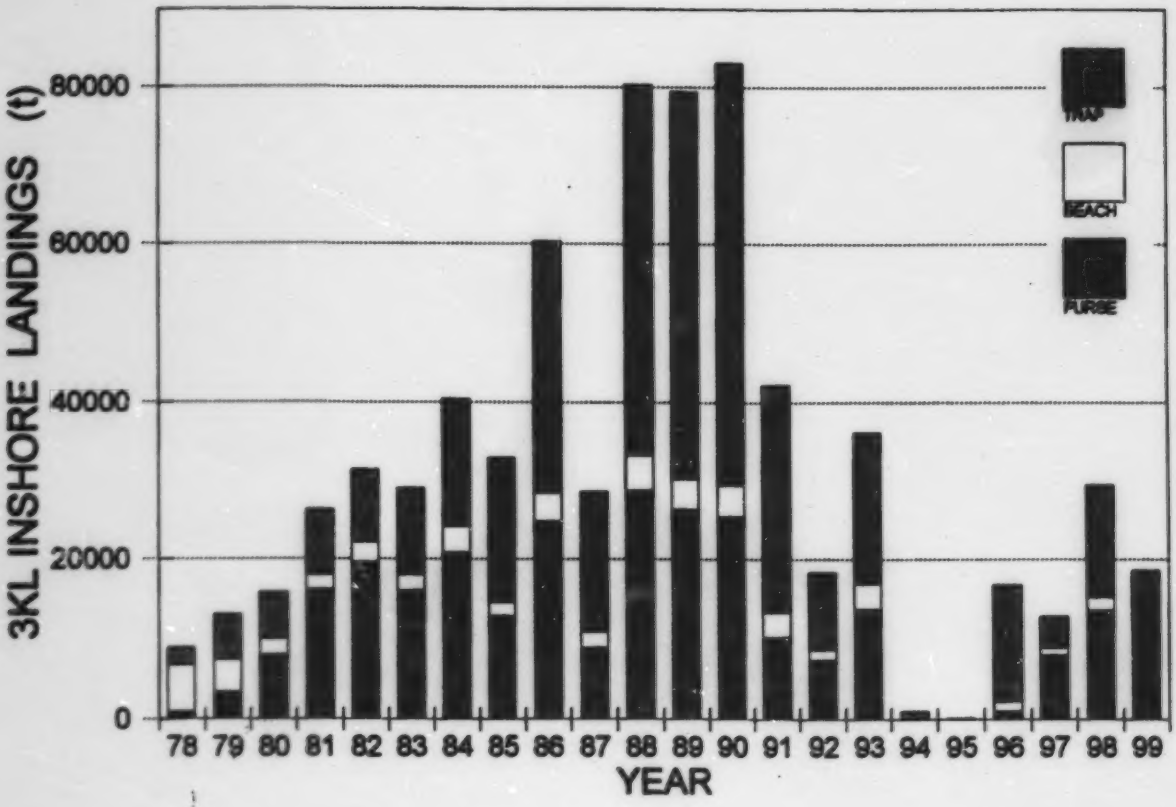


Fig. 2. Inshore capelin landings (t) in Div. 3KL.

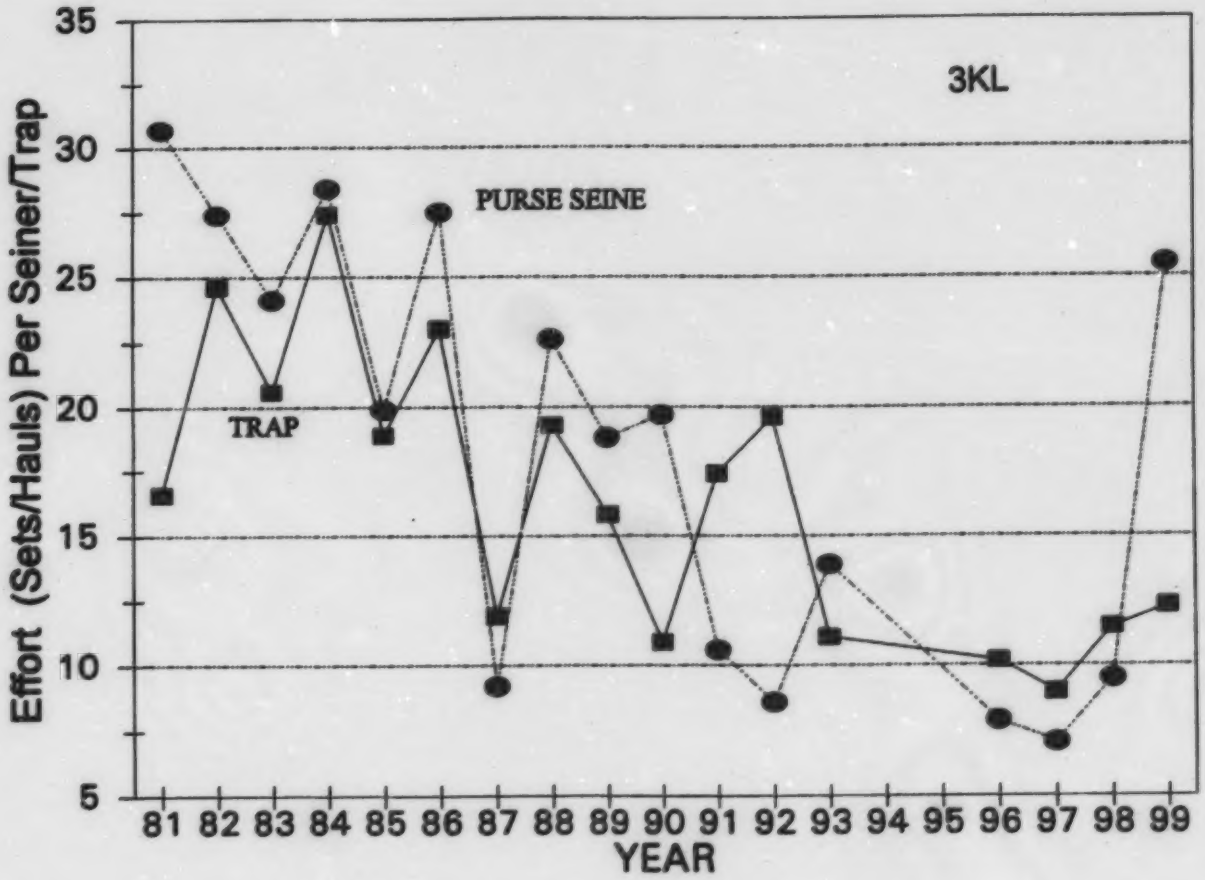


Fig. 3. Trends in average fishing effort for trap hauls (square) and purse seine sets (circle).

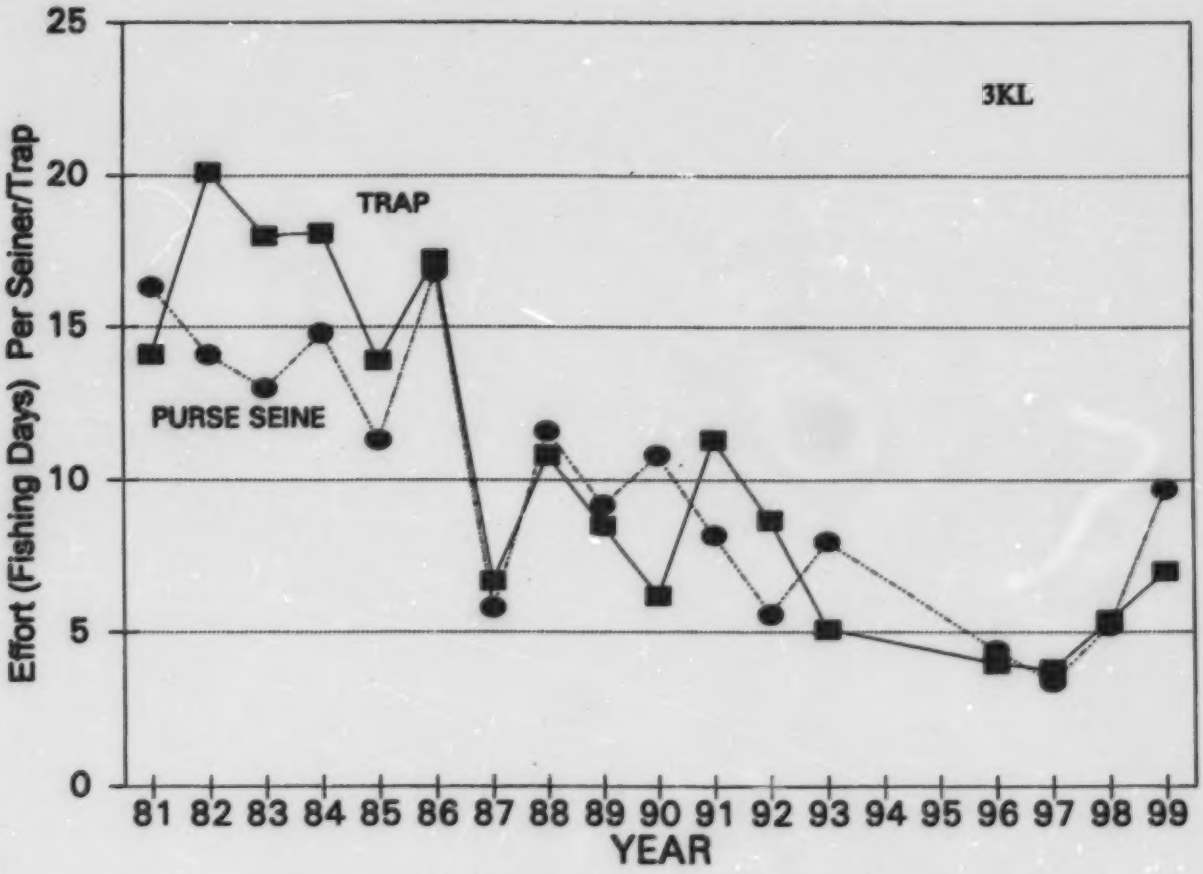


Fig. 4. Trends in average fishing effort for trap fishing days (square) and purse seine searching days (circle).

Appendix A

2000 Capelin Allocations

NAFO Area	Coastal area	Quotas (tonnes)		
		Fixed gear	Purse seine	Total
2J	Labrador	150	-	150
3K	White Bay	4475	1500	5975
	Notre Dame Bay	5925	1500	7425
Totals - 3K		8400	3000	13400
3L	Bonavista Bay	2495	1425	3920
	Trinity Bay	4490	1870	6360
	Conception Bay	3710	3560	7270
	Southern Shore	2300	0	2300
	St. Mary's Bay	500	1680	2180
Totals - 3L		13495	8535	22030

2000 Capelin Quotas - Fixed Gear Sub-divisions

Area	Sub-division	Quota
White Bay	Cape Bauld to Fischot Island	965
	Fischot Island to Cape Fox	325
	Cape Fox to Hampden, inclusive	1275
	Bottom of Bay to Cape St. John	1910
Notre Dame Bay	Cape St. John to North Head	1675
	North Head to Dog Bay Point	3470
	Dog Bay Point to Cape Freels	780
Southern Shore	Cape St. Francis to Long Point	600
	Long Point to Cape Neddick	400
	Cape Neddick to Cape Pine - IQ	114
	Cape Neddick to Cape Pine - Competitive	1186

Appendix B

1999 Opening and Closing Dates

Mobile Gear

St. Mary's Bay - June 28-July 31

Conception Bay - June 28-July 31

Trinity Bay - June 28-July 2

Bonavista Bay - June 28-July 6

Notre Dame Bay - June 28-July 12

White Bay - June 28-July 13

Fixed Gear

St. Mary's Bay - didn't open

Southern Shore:
- Cape St. Francis to Long Point - didn't open
- Long Point to Cape Neddick - didn't open
- Cape Neddick to Cape Pine - didn't open

Conception Bay - July 7-31

Trinity Bay - July 4, July 7-31

Bonavista Bay
- Cape Freels to Connecting Point - July 9-31
- Connecting Point to Cape Bonavista - Didn't open

Notre Dame Bay:
- Cape St. John to North Head - July 5-31
- North Head to Dog Bay Point - July 5-31
- Dog Bay Point to Cape Freels - July 13-31

White Bay:
- Cape Bauld to Fischot Island - July 5-31
- Fischot Island to Cape Fox - July 7-14
- Cape Fox to Hampden - July 5-13
- Hampden to Cape St. John - July 15-20

Distribution and biological characteristics of capelin in Northeastern Newfoundland waters during May 1999.

by

F. K. Mowbray

Introduction

The capelin stock of NAFO divisions 2J3KL constitutes an important component of the Northeast Newfoundland marine ecosystem. The stock has been exploited over the years by both inshore and offshore fleets and is an important source of prey for the region's Atlantic cod stock, seabirds and marine mammals. After an expansion of the offshore fleet, and near collapse of the capelin stock in the late 1970s a Canadian acoustic survey was established with the aim of assessing capelin biomass and distribution. Surveys were conducted with varied levels of success in both the spring and the fall through the 1980s until 1992. In 1993 the spring survey was displaced in favour of an expanded fall survey, which was since terminated in 1994. Subsequently, except for the current expedition, only one survey (May 1996) has been conducted. Nonetheless, these acoustic surveys represent the most comprehensive and extensive time series available on offshore capelin distribution and abundance.

During the period that both spring and fall surveys were conducted spring survey estimates were thought to be the most reliable of the two as they best corresponded with inshore indices of abundance. In many ways spring is a natural time to attempt surveying Newfoundland capelin stocks. In the spring the stock tends to be distributed over a smaller area and the capelin more aggregated than during fall feeding season. However spring surveys also have several vulnerabilities. In order to be successful the timing and location of the survey must overlap that of the spawning migration of the maturing adults (ages 3-6), as well as the distribution area of the immature (mostly one and two year old) fish. In addition the survey area must be accessible (ice free) during this critical period. The spring survey during the mid and late 1980s apparently avoided these pitfalls with good numbers of both immature and maturing capelin found consistently within the survey area (3L) during the month of May. However, starting in 1991, things began to change.

During the 1990s fall distributions of capelin within 2J3KL contracted and shifted southwest (Frank et al. 1996). Timing of migrations and spawning was delayed (Nakashima 1994, Shackell et al. 1994, Carscadden et al. 1997) and capelin biomass estimates from spring and fall acoustic surveys plummeted. For the first time inshore and offshore abundance indices diverged with inshore indices remaining high throughout the decade while offshore indices collapsed. As a result the reliability and performance of the offshore acoustic surveys were called into question. A number of potential causes for the sudden decline in the acoustic biomass were investigated including interactions of survey timing and delayed spawning (Winters 1995), effect of changes in vertical migration (Shackell 1994b), and the distribution of survey effort relative to the changing distribution of the stock (Miller 1995, Frank et al. 1996).

In re-establishing spring acoustic surveys it is vital that the problems of the early 1990s be addressed. Perhaps the most essential of these considerations is re-defining our model of spatial distribution, migration and timing. As pointed out by (Vihjálmsson 1994) knowing the distribution and movement pattern of a stock is paramount to designing and conducting a successful acoustic survey of capelin biomass. In May 1999 the traditional spring stock area was surveyed for the first time in several years. The primary objectives of the survey were to delineate the extent of the stock's distribution, examine large (> 100 km) and meso scale (0.1 km-10 km) variations in abundance, investigate behavioural and biological characteristics, and to relate these attributes to the surrounding environmental conditions. This paper presents a summary of the survey findings and is intended for use as a reference point for further investigation. Biomass estimates are presented strictly for the purposes of examining large scale variability in biological characteristics and stock composition, and are not considered a measure of stock status.

Methods

Acoustics

The survey was conducted from May10 – May 28 in the offshore area from 48 to 50 degrees latitude, from the 100 m nearshore contour (west) to the 500 m contour (east). A portion of the survey time was also spent in each of three bays, Trinity Bay, Bonavista Bay and Notre Dame Bay (Figure 1). Acoustics were conducted from the research vessel CCGS Teleost travelling at an average speed of 8 knots. The vessel was equipped with calibrated hull mounted split beam 38 and 120 kHz transducers and an EK500 echosounder system which was used to produce high resolution (10 cm vertical bins, ping interval 1.5 secs) backscatter volume (Sv) measurements. Sv measurements were collected from the Ethernet output of the EK500 using the Canadian DAT acquisition software CH1 (See Appendix 1 for details on system configuration, acquisition). Echogram files were subsequently edited and integrated with the DAT program CH2 using an integration Sv threshold of -85dB. Target strength distributions for both transducers were calculated by the EK500, output at 15 minute intervals on printed echograms and used to help differentiate between fish and crustacea (Simard and Lavoie 1999). Echograms (38 kHz only) were edited to remove noise from scanmar, whales or

other ambient sources. Bottom echo protrusions and slope shadowing were also removed (Appendix 2). Echogram mark characteristics such as shape and density were used in combination with target strength distribution information to identify those characteristic of fish. These marks were subsequently classified as capelin, possibly capelin, capelin mix or cod (Appendix 2). Sv values for the 38 kHz were integrated for over the whole water column in 10 m surface referenced layers and 100m horizontal bins to produce back-scatter area (Sa) estimates in m^2/m^2 for each classification type (MacLennan and Simmonds 1992). These values were then scaled to numbers of individuals per square meter by dividing Sa by $\sigma_{(bs)}$ derived using the following target strength relationships:

Capelin	20 logL-73.1	where L is length in cm (Rose 1999)
Cod	20 logL-67.5	where L is length in cm (Rose unpublished)
Arctic Cod	21.8 logL-72.7	where L is length in cm (Gjøsæter and Ushakov 1997)

Estimates for capelin provided in this document are those for marks recognised unambiguously as capelin plus the capelin portion of 'mixed' scatterers. Backscatter attributed to 'mixed' species was partitioned using the catch amounts, TS properties and biological characteristics of capelin, cod and arctic cod in trawl catches. No attempt was made to identify scatter produced by shrimp as they tended to remain in the ground shadowing zone and in medium to moderate densities unlikely to have produced backscatter in excess of the integration threshold. Arctic cod distributions presented herein are those resulting from the partitioning of 'mixed' marks. However, cod backscatter is presented for those marks identified as cod, as opposed to the 'cod' portion of mixed species marks (Appendix 2).

Fishing and biological sampling

Fishing sets were conducted when new or different fish marks were observed on the sounder in order to obtain estimates of species composition and samples of biological characteristics of scatterers (Figure 1). Three bottom trawl fishing sets were also conducted when no marks were visible on the echo sounder. Total numbers and catch weights were recorded for all species and length frequencies taken for all finfish except capelin. For capelin catches, length, sex and maturity were recorded for a random sample of up to 200 fish. Total weight and gonad weight were measured and sex and gonad maturity stages recorded for a length stratified sub-sample of two fish per sex per 5 mm length class. Otoliths of sub-sampled fish were removed and stored for subsequent age determination. CTD casts were made at all set locations in addition to a gridwork of XBT profiles (Figure 1).

Results

Capelin were found at densities of at least ($0.005/m^2$) over most of transects 11,12 and 13, except in the shallow waters (<150 m) on the northern Grand Bank (Figure 2). The highest capelin densities occurred in Trinity and Bonavista Bay though higher density

areas were also occurred along the shelf edge, in a small canyon around 48° N, 51° 45' W, and in the Bonavista corridor. Capelin were seldom found in highly aggregated schools typical of the later 1980s, but rather tended to be distributed in even 'carpet-like' layers near bottom, often mixed with other species such as arctic cod (Figure 3), shrimp (Table 1) and occasionally Atlantic cod (Figure 4).

Immature (age one) fish were found in Trinity Bay and the surrounding area as far as 51° East (Figure 2). Older (2+) immatures were found in all capelin aggregations except those in Notre Dame Bay. Immature 2 year olds amounted to nearly half of the capelin found along the shelf edge. Biological data was not available for capelin aggregations in the Bonavista corridor as high densities of crab fishing gear prevented trawling. However, based on the similarity of the Bonavista corridor marks with those directly west, backscatter in this area was classified as 'capelin mix' and partitioned using the nearest set westward.

Horizontal capelin distribution may be linked to water temperature. An examination of water temperature characteristics revealed that capelin were mostly excluded from areas where bottom temperatures neared zero (Figure 5). In offshore areas peak capelin densities mostly occurred within 50 m of the bottom except in those regions where bottom depths exceeded 300m, but there was no obvious correspondence between the height of plus zero degree water consecutive to the bottom and the height of peak capelin density (Figure 6.). Capelin inshore occupied various parts of the water column, and in some instances appeared to have been undergoing diel migrations.

Vertical distribution of capelin may be linked to size or length. At seven sites repeat fishing tows were made, one on bottom using the Campelen trawl, and a second with the IYGPT. The IYGPT was usually fished higher in the water column, depending on the vertical range of the capelin distribution. Length frequencies from each gear's catch are compared by trawl site in Figure 7. As is evident from the echograms associated with these sets, in some cases there appeared to be only one distinct layer of fish while in other cases there were plumes reaching up into the water column (Appendix 3a-3c). Without considering gear selectivity it would appear from these results that the proportion of small fish increases with distance from the bottom with very small fish occurring only above bottom and the largest fish occurring most frequently near bottom. This size gradient seems more pronounced during day than at dawn, dusk or night. However, considering that the two gears have quite different mesh sizes we must query how much of this vertical gradient may be due to gear selectivity. In order to address this concern data from an experiment conducted in 1995 was examined. The 1995 data was considered more suitable for examining relative selectivity since in most cases the range between fishing depths of the two gear types was smaller than in the 1999 experiment. Of the seven comparative fishing sites sampled in 1995 only two showed any marked difference between gears in the length composition of the capelin catch (Appendix 4). However, in all cases the range of small fish sampled by the IYGPT appears greater than those caught by the Campelen which rarely caught anything less than 120 mm in either experiment. Escapement of small (mostly age one) capelin from the Campelen trawl is most evident in Sets 8 and 9 of the 1999 survey (Figure 7).

Diel variation in the acoustic dectectability of capelin was exhibited at the mesoscale study sites. Night-time density (Sa) estimates at both sites were higher (Pass 2 at Cape Spear and Pass 1 at the Shelf edge) than during the day although this difference was only statistically significant at the Shelf Edge site (ANOVA with log transformed Sa values, $F=2.86$, $P<0.05$, $n=238$). Capelin at the Cape Spear site were more aggregated, resulting in greater variability both within and between transects (Appendix 5). As a result, although differences among transects and passes (day, night and 14 days later) were greater than at the Shelf Edge site, these differences were not statistically significant (ANOVA $F=1.05$, $P>0.05$). Capelin density during a third night-time pass at Cape Spear made two weeks later was only 25% percent of the earlier measure although a Campelen set made at this time had the largest capelin catch of the survey. These fish were also on average larger than in the previous passes with many of the immature age two fish having left.

Given the survey design, transect spacing and use of multiple sampling gears with unknown selectivity factors the calculation of a biomass estimate from this data seems premature. However in order to compare stock distribution by age or maturity stage it is necessary to perform some sort of area extrapolation. Consequently a biomass estimate has been produced for each stratum using the mean density n/m^2 of all samples taken within the stratum and partitioned using the age and maturity composition of the trawl catches pooled by stratum.

Of the offshore strata W300 had the highest mean capelin density and contributed almost 50% of the survey area's capelin biomass (Table 3). It contained roughly three quarters of all three year old fish surveyed, with approximately 40%, 92% and 99% respectively of the maturing age 2, 3 and 4 fish (Table 4). Capelin densities in W200, E300 and E200 were very similar although W200 contributed most to the biomass due to its larger size. W200 also differed in composition being the only offshore stratum in which age one fish were present and the one where the proportion of maturing age 2 fish (68%) was highest. W200 contained over half of all the maturing age 2 fish surveyed. Stratum E300 was also dominated by age 2 fish, two thirds of which were immature. Age and maturity samples were not available for E500, N500 and E200 so abundance and biomass was calculated using biological characteristics from sets in adjacent strata, biomass contained by these areas was low (Table 3). Overall, the surveyed offshore area was estimated to contain 117, 090 tons of capelin. Biomass estimates for the three bays are not given, since the transect design/realisation in these areas was not conducive to biomass estimation. Nonetheless, densities in Trinity were three times greater than the highest levels seen offshore, while densities in Bonavista were twice as great. Capelin densities in Notre Dame (ND) were low, comparable to the low offshore strata. Two year-olds accounted for 55% of capelin in Trinity of which 20 % were maturing (Table 5). These age two Trinity Bay fish were also the smallest at age in the entire survey. In contrast age 2 capelin in ND Bay were the largest surveyed with the greatest portion (90%) of maturing members. No ages or maturity information was available for inner Bonavista Bay.

Discussion

The 1999 survey did not include the southern portion of the area surveyed in 1996, but extended further north than in prior spring surveys. Before 1996 no survey reached beyond 49 degrees latitude. The reasons for this change were two-fold. First, given the vessel time allotted for the survey it was impossible to adequately cover the entire area. Consequently it was decided to concentrate on regions of historical importance for immature age 2 fish, at the risk of missing maturing fish not yet arrived. Second, an atypical ice-free year allowed the opportunity to profit from surveying further north in a region which had reasonable densities of capelin in 1996. This provided a rare opportunity to compare pre-spawning biological characteristics of fish from this area with those further south.

During the most recent (1996) spring acoustic survey most of the capelin biomass above 48° latitude (Miller 1997). Capelin were again found in this area in 1999 but also furthur north and south. In both years the biomass tended to be distributed primarily in waters between 200 and 300 m, with no fish found in the shallow waters of the northern Grand Bank. The distribution pattern in stratum E300 was similar to that seen in the late 1980s, including the presence of capelin (and small cod) in the Bonavista corridor. Though overall 1999 densities remain an order of magnitude less than in the previous time period.

One of the most striking features of the 1999 survey was the lack of immature age 2 capelin. In years of high abundance immature age 2 were found throughout the northern survey area (above 48°) and were estimated to contribute up to 40% of the biomass (Miller 1997). In 1999 immature age 2 capelin were found mostly on the Shelf break and in Trinity and Bonavista Bays and accounted for less than 25% of fish surveyed. One interpretation of this result would be that the distribution of immature 2 fish has shifted out of the survey area but perhaps a more credible hypothesis would be that a higher proportion of age 2 fish are maturing. This interpretation would be in keeping with reported reductions in the size at age of spawners. The shift in distribution of immature age 2 fish may warrant further investigation. There is some evidence that the distribution of age 2 capelin may be temperature dependent. In a recent study Marchand et al. (1999) found that age 2 capelin in the St. Lawrence estuary were predominately associated with water temperatures in excess of 2 °C. It appeared that these fish migrated vertically (toward the surface) to avoid the increased CIL associated with upwelling during flood tides, moving horizontally when the CIL reaches the surface. A more thorough examination of water temperature and capelin distribution off Newfoundland may reveal whether a similar mechanisms are at work here. There is certainly ample evidence of changes in vertical distribution and movement patterns over the past two decades.

Capelin distributions surveyed since the 1980s have shown a distinct change in vertical distribution. Shackell (1994a) showed that the range of vertical (diel) migrations varied among years, but was reduced to such small amounts in 1991 and 1992 that day-night differences in the mean depth of aggregations were no longer statistically significant. Similar patterns in vertical migration were obtained during the 1999 survey. While the reason for these changes was not explicitly tested, the results seem to indicate that size

composition may have a role. However, before one can test/quantify effects of fish size we must first address the problem of gear selectivity/efficiency. Understanding and quantifying the effects of vertical structure and gear selectivity is of vital importance in the interpretation of acoustic data sets. There are two reasons for this: 1) Sampling biased toward one size range will result in target strength estimates not applicable to the whole water column backscatter; a bias that can seriously affect estimation of population abundance; and 2) Age composition as deduced from biased biological sampling can impair the ability to track cohort strength.

Proper dis-aggregation of backscatter into age groups is also needed to examine age related horizontal distribution, e.g. comparing capelin in the bays to those offshore. In this study densities of capelin in Trinity and Bonavista Bay far exceeded those found offshore and would likely contribute significantly to the total abundance. However, how the contribution of 'Bay' capelin has changed overtime cannot be assessed since there is no information on biomass inshore prior to the early 1990s and only a few observations within the last decade (Miller 1997, O'Driscoll et al., 2000). At present we have no way of determining whether preferential distribution inshore versus offshore aggregations are part of an ontogenetic migration or whether they simply reflect different stock components. Since age 1 capelin are poorly recruited to, or identified by, either the trawl or acoustics our estimation of inshore and offshore abundance at early ages may be biased and our ability to detect any ontogenetic migrations hampered.

In addition to these concerns is the problem of species mixing. As demonstrated in Figure 3 Arctic cod is mixed with capelin over a fairly large portion of the capelin range. Similarly shrimp are mixed with capelin in some of the same areas as arctic cod, as well as in areas with capelin only. If the survey were extended south capelin would undoubtedly be found mixed with sandlance as well (O'Driscoll et al., 2000). Using catch information to partition catches in these situations is risky and not recommended (MacLennan and Simmonds 1992). Using trawl catches the assumes that catchability is the same or known for all species. However this is not the case. In a recent examination of arctic cod, capelin and sandlance catches in Campelen bottom trawls, Lilly and Simpson (2000) suggested that Arctic cod are probably the most susceptible of the three to capture by this gear. At present it is unclear how this problem could be resolved. Acoustically, target strength of capelin is very similar to slightly larger arctic cod so this is a poor criteria for differentiating between these two species. Target strength could however be of some help partitioning sandlance and shrimp, both of which have a considerably lower target strength than capelin.

Although this study has identified several areas requiring further work, it also represents a large step forward in acoustic surveillance. The digital echosounder employed in this survey, when used in combination with powerful visual analysis and editing tools such as CH2 and real time in-situ target strength distributions makes the analysis of the data much more robust to user subjectivity. The increased power and lower signal to noise ratio of this system has increased the functional range of the acoustics from 200 m to nearer 500m. The new editor provides a tool to examine not only capelin but all identifiable species in one pass through the data, in effect regarding the ecosystem as

whole instead of assessing one species. Backscatter volume samples are collected at a low, repeatable threshold (a nearly impossible feat with an analogue sounder) and appropriate integration threshold levels can be examined post acquisition so that the fish are not lost along with the noise. Identifying and removing bottom is simplified, and concerns of acoustic extinction due to dense schooling are removed. There remain concerns over ground shadowing effects which results in a dead zone of 0.73 m, and the potential for missing fish schooling in the 15 m above the effective range of the transducer.

At this point in time the most pertinent and tractable problems are knowledge of capelin biology and behaviour and our tenuous ability to collect representative biological samples. It is recommended that the best way to address these concerns is by a continuation of the mesoscale studies with modules for gear selectivity and catchability similar to those carried out in 1999. These mesoscale studies can be built into a two stage sampling design where finer scale sampling is conducted in the second stage conducted only in areas of significant densities. Such a strategy will allow for a gross delimitation of capelin distribution and expansion of the sampled area while maintaining adequate sampling levels in areas of capelin concentrations.

References

Carscadden, J.E., Nakashima, B.S. and K.T. Frank. 1997. Effects of fish length and temperature on the timing of peak spawning in capelin. Can. J. Fish. Aquat. Sci. 54 : 781-787.

Frank, K.T., J.E. Carscadden and J.E. Simon. 1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Can. J. Fish. Aquat. Sci. 53: 1473-1486.

Gjøsæter, H. and N.G. Ushakov. 1997. Acoustic estimates of Barents Sea Arctic cod stock (*Boreogadus saida*) in Proceedings forage Fishes in Marine Ecosystems, 485-504.

Lilly, G. and M. Simpson. 2000. Distribution and biomass of capelin , Arctic cod and sand lance on the Northeast Newfoundland Shelf and Grand Bank as deduced from bottom-trawl surveys. DFO Atl. Fish. Res. Doc. 2000/091.

Marchand, C., Simard, Y., Gratton, Y. 1999. Concentration of capelin (*Mallotus villosus*) in tidal upwelling fronts at the head of the Laurentian Channel in the St. Lawrence estuary. Can. J. Fish. Aquat. Sci 56: 1832-1848.

MacLennan, D.N. and Simmonds, J.E. 1992. Fisheries Acoustics. Chapman and Hall, London.

Miller, D.S. 1995 Results from and Acoustic survey for capelin (*Mallotus villosus*) in NAFO Divisions 2J3KL in autumn of 1994. In Capelin in SA2 + Div 3KL. DFO Atl. Fish. Res. Doc. 95/70: 63-71.

Miller, D.S. 1997 Results from an acoustic survey for capelin (*Mallotus villosus*) in NAFO Divisions 3KL in the spring of 1996. In Capelin in SA2 + Div 3KL. DFO Atl. Fish. Res. Doc. 97/29: 84-90.

Nakashima, B.S. 1994. The relationship between oceanographic conditions in the 1990s and changes in spawning behaviour , growth and early life history of capelin (*Mallotus villosus*). NAFO SCR Doc. 94/74.

O'Driscoll, R.L., G.A.Rose, Anderson,J.T. and Mowbray, F. 2000. Spatial association between cod and capelin: a perspective on the inshore-offshore dichotomy. DFO Atl. Fish. Res. Doc. 2000/083 23p.

O'Driscoll, R.L., Anderson,J.T. and Mowbray, F. 2000. Abundance and distribution of capelin from an acoustic survey in conjunction with the 1999 Pelagic Juvenile Survey. In Capelin in SA2 + Div 3KL. DFO Atl. Fish. Res. Doc. - this volume.

Rose, G.A. 1998. Acoustic target strength of capelin in Newfoundland waters. ICES Journal of Marine Science, 55: 918-923.

Shackell, N.L., Carscadden, J.E. and D.S. Miller. 1994a. Diel migration of capelin (*Mallotus villosus*) and its effect on acoutic estimates of density. In Capelin in SA2 + Div 3KL. J. Carscadden ed. DFO Atl. Fish. Res. Doc. 94/18: 109-126.

Shackell, N.L., Carscadden, J.E. and D.S. Miller. 1994b. Migration of pre-spawning capelin (*Mallotus villosus*) as related to temperature on the northern Grand Bank, Newfoundland. ICES J. Mar. Sci. 51: 107-114.

Simard, Yand D. Lavoie. 1999. The rich krill aggregation of the Saguenay – St. Lawrence Marine Park: hydroacoustic and geostatistical biomass estimates , structure, variability and significance for whales. Can. J. Fish. Aquat. Sci 56: 1182-1197.

Vihjálmsson, H. 1994. The Icelandic capelin stock. Rit Fiskideildar, Journal of the Marine Institute Reykjavik. Vol 13. 281 p.

Winters, G.H. 1995. Interactions between timing, capelin distribution and biomass estimation from Div. 2J3KL capelin acoustic surveys. In Capelin in SA2 + Div 3KL. J. Carscadden ed. DFO Atl. Fish. Res. Doc. 95/70: 167-179.

Table 1. Details of biological samples collected during spring acoustic survey in NAFO Divisions 3L and 3K in May 1999.

Set	Transect	Gear	Light	Fishing Depth (m)	Bottom Depth (m)	Duration (minutes)	Fil. Vol. (m^3)	Capelin catch (numbers)	Catch weight (kg)			
									Capelin	Atlantic cod	Artic cod	Shrimp
1	TB	IYGPT	Dark	27	0196	17	57883	219	0.84	0	0	0.01
2	TB	IYGPT	Dawn/dusk	23	0136	21	84695	466	7.87	0	0.00	0.00
3	TB	IYGPT	Daylight	245	0335	15	93379	113	0.46	0	0.57	2.54
4	10	Campelen	Dark	170	0174	15	79210	160	2.40	0.05	0.30	0
5	10	Campelen	Dark	165	166	22	80207	811	13.70	0.36	0.95	2.41
6	10	IYGPT	Dark	150	160	23	84571	19	0.22	0	0.01	0
7	10	IYGPT	Daylight	m	0166	22	NA	124	1.01	0	0.01	0
8	10	IYGPT	Daylight	148	0163	30	140748	564	2.54	0	0.06	0.02
9	10	Campelen	Daylight	139	270	30	89675	1731	29.25	0.09	1.05	0
10	10	IYGPT	Daylight	19	0121	15	76903	0	0.00	0	0	0
11	10	Campelen	Daylight	98	95	15	62907	4	0.08	0	0	0
12	10	Campelen	Daylight	m	198	15	NA	635	8.35	0	0.35	0.45
13	11	Campelen	Daylight	347	347	15	69087	15	0.29	8.10	0	24.90
14	11	Campelen	Daylight	218	220	15	70358	848	10.05	0	1.10	10.75
15	11	IYGPT	daylight	68	0221	15	76354	0	0.00	0	0.00	0.00
16	11	IYGPT	daylight	202	0223	15	78423	73	0.58	0	0	0
17	11	IYGPT	daylight	130	226	30	149846	51	0.06	0	0	0
18	11	Campelen	daylight	225	226	15	76436	6680	91.85	0	19.10	0.50
19	Unsuccessful	Campelen	daylight	.	.	.	.	.	.	.	.	.
20	12	Campelen	dark	273	259	16	75231	473	6.95	5.30	1.11	44.75
21	12	Campelen	daylight	255	0263	16	85142	6378	127.55	0.12	0.43	223.96
22	12	IYGPT	daylight	235	0254	15	73995	812	9.95	0	0	4.11
23	12	IYGPT	daylight	233	0265	30	NA	133	1.66	0	0	0
24	12	IYGPT	daylight	207	0260	15	70998	147	2.04	0	0	0
25	12	Campelen	daylight	255	0260	20	89083	1734	32.51	0.87	0.16	163.49
26	12	Campelen	daylight	236	236	16	89239	1252	15.65	0.03	0.95	3.20

Table 1. (Continued)

Set	Transect	Gear	Light	Fishing Depth (m)	Bottom Depth (m)	Duration (minutes)	Fil. Vol. (m^3)	Capelin catch (numbers)	Catch weight (kg)			
									Capelin	Atlantic cod	Artic cod	Shrimp
27	12	IYGPT	daylight	226	0240	15	NA	2392	20.94	0	0.02	0.05
28	12	Campelen	daylight	278	274	15	78212	60	0.59	3.45	0	4.40
29	12	Campelen	daylight	440	440	15	79451	0	0.00	32.40	0	0.10
30	12	Campelen	daylight	246	246	15	77887	574	9.56	0.95	0.68	155.39
31	12	Campelen	daylight	205	0296	20	161332	49	0.58	0	0	0.62
32	13	Campelen	dark	254	0334	15	79451	1530	27.70	0	0	0
33	Unsuccessful	IYGPT	dark	.	.	.	.	.	.	.	.	.
34	BB	IYGPT	daylight	252	300	16	102713	68	0.65	0.03	0.05	0.01
35	BB	Campelen	dark	277	0311	20	154072	559	7.15	0	0.34	0
36	BL	Campelen	daylight	251	322	20	162746	70	0.80	0	0	0
37	BL	Campelen	daylight	334	334	15	66195	33	0.73	1.85	0	284.85
38	BL	Campelen	daylight	323	323	15	33195	0	0.00	0.45	0	17.85
39	BL	Campelen	dark	335	545	15	104104	0	0.00	0	0	0
40	14	Campelen	daylight	308	0311	17	90044	26	0.55	1.20	0.01	113.60
41	NDB	Campelen	dark	237	238	20	105934	235	3.66	0.70	1.76	16.55
42	NDB	Campelen	daylight	250	0295	16	103021	33	0.54	0	0.02	0.15
43	NDB	Campelen	daylight	277	277	15	67364	138	2.99	2.45	7.76	31.05
44	TB	Campelen	daylight	227	0260	15	79451	3883	41.75	0	0.01	0
45	10	Campelen	dark	159	156	28	148308	18298	384.25	0.20	0.60	10.60

Table 2a. Average area back-scattering (Sa * 10^{-6}) of capelin aggregations at two meso-scale study sites off Northeastern Newfoundland, May 1999.

		Pass 1 – May 14		Pass2 – May 14		Pass 3 – May 28	
Study Site	Transect	Mean	SD	Mean	SD	Mean	SD
Cape Spear	A	2.89	9.09	5.56	11.92	0.07	0.06
	B	14.85	65.22	6.92	26.00	3.19	8.81
	C	0.34	0.86	1.50	4.58	3.63	9.59
	D*	0.37	0.77	1.98	8.58	0.07	0.12
	E*	0.82	2.89	12.71	38.51	0.18	0.49
	ALL	**3.85**	**15.77**	**5.73**	**17.92**	**1.43**	**3.81**

Table 2b.

		Pass 1 – May 18		Pass 2 – May 19	
Study Site	Transect	Mean	SD	Mean	SD
Shelf Edge	A	3.42	4.23	1.32	2.54
	B	3.32	2.55	4.04	3.71
	C	3.03	3.42	2.32	2.24
	D	3.01	2.12	1.62	2.24
	E	2.04	3.21	0.51	0.19
	ALL	**2.96**	**3.11**	**1.96**	**2.18**

* Only western half of transect covered in Pass 3.

Table 3. Estimates of abundance and biomass for capelin in surveyed offshore areas of NAFO Divisions 3L and 3K during May 1999.

Stratum	Number 100m bins	Capelin density (n/m^2)	Stratum area (km^2)	Stratum abundance ($n*10^6$)	Mean weight (kg)	Stratum biomass (tons)
E200	4776	0.01558	13529	211	0.0128	2.698
E300	1191	0.16549	7415	1227	0.0151	18.530
E500	1171	0.07562	1977	149	0.0151	2.257
W200	2349	0.15176	12615	1914	0.0128	24.504
W300	3022	0.49371	7533	3719	0.0160	59.507
N500	1643	0.06966	8608	600	0.0160	9.594
Total Offshore	14152	0.16197	51677	8370	0.0146	117.090
Trinity Bay	2310	1.788	.	.	0.0061	.
Bonavista Bay	2421	1.036	.	.	.	.
Notre Dame Bay	3025	0.0847	.	.	0.0200	.

Table 4. Extrapolated age and maturity composition of capelin surveyed offshore during an acoustic survey in May 1999. Numbers at age are given in millions of individuals, LSMs and Ages are number sampled.

Stratum	Variable	Age 1	Age 2	Age 3	Age 4	Age 5	Unknown	LSMs	Ages
W200	Number	402	913	565	31	0	4	865	51
	Percent	21	47.7	29.5	1.6	0	0.2		
	% mature	0	67.7	96.9	100	.	0		
	Mean length (mm)	72	140	156	165	.	113	143	
	Mean weight	1.1	13.3	19.8	23.2	.	5.4	14.4	
E300	Number	0	778	422	26	1	0	2213	55
	Percent	0	63.4	34.4	2.1	0.1	0		
	% mature	.	30.8	93	100	100	.		
	Mean length (mm)	.	135	159	164	175	.	148	
	Mean weight	.	11.6	21.2	23.2	28.4	.	16.8	
W300	Number	0	1514	1990	216	0	0	519	43
	Percent	0	40.7	53.5	5.8	0	0		
	% mature	0	39.6	92.3	98.9	.	.		
	Mean length (mm)	.	131	156	160	.	.		
	Mean weight	.	10.4	19.6	21.2	.	.	16.0	
E200	Number	.	.	.	.	.	4	4	0
	Percent	.	.	.	.	.	100	.	
	% mature	.	.	.	.	.	.	.	
	Mean length (mm)	.	.	.	.	.	158	158	
	Mean weight	.	.	.	.	.	.	.	
E500	Number	.	.	.	.	.	15	15	0
	Percent	.	.	.	.	.	100	.	
	% mature	.	.	.	.	.	.	.	
	Mean length (mm)	.	.	.	.	.	158	158	
	Mean weight	.	.	.	.	.	.	.	
N500	Number	.	.	.	.	.	59	59	0
	Percent	.	.	.	.	.	100		
	% mature	.	.	.	.	.	.		
	Mean length (mm)	.	.	.	.	.	162	162	
	Mean weight	.	.	.	.	.	.		

Table 5. Age and maturity composition of capelin caught inshore during an acoustic survey in May 1999. Numbers at age, LSM and ages are given as the number of fish sampled.

Stratum		Age 1	Age 2	Age 3	Age 4	Age 5	Unknown	LSMs	Ages
TB	Number	407	598	65	9	.		1084	55
	Percent	37.5	55.2	6	0.8	.	0.5		
	% mature	0	20	81.2	100	.	50		
	Mean length (mm)	58	125	149	154	.	138		
	Mean weight	0.3	8.6	16.5	18.3		14.9		
BB	Number	.	.	.	.		68	68	0
	Percent	.	.	.	.		100		
	% mature	.	.	.	.		.		
	Mean length (mm)	.	.	.	.		130		
	Mean weight	.	.	.	.		.		
NDB	Number	0	102	226	36	2	5	371	57
	Percent	0	27.5	61	9.7	0.6	1.3		
	% mature	.	89.6	99.9	100	100	80.7		
	Mean length (mm)	.	147	158	166	173	183		
	Mean weight	.	16.1	20.8	24.7	27.1	33.8		

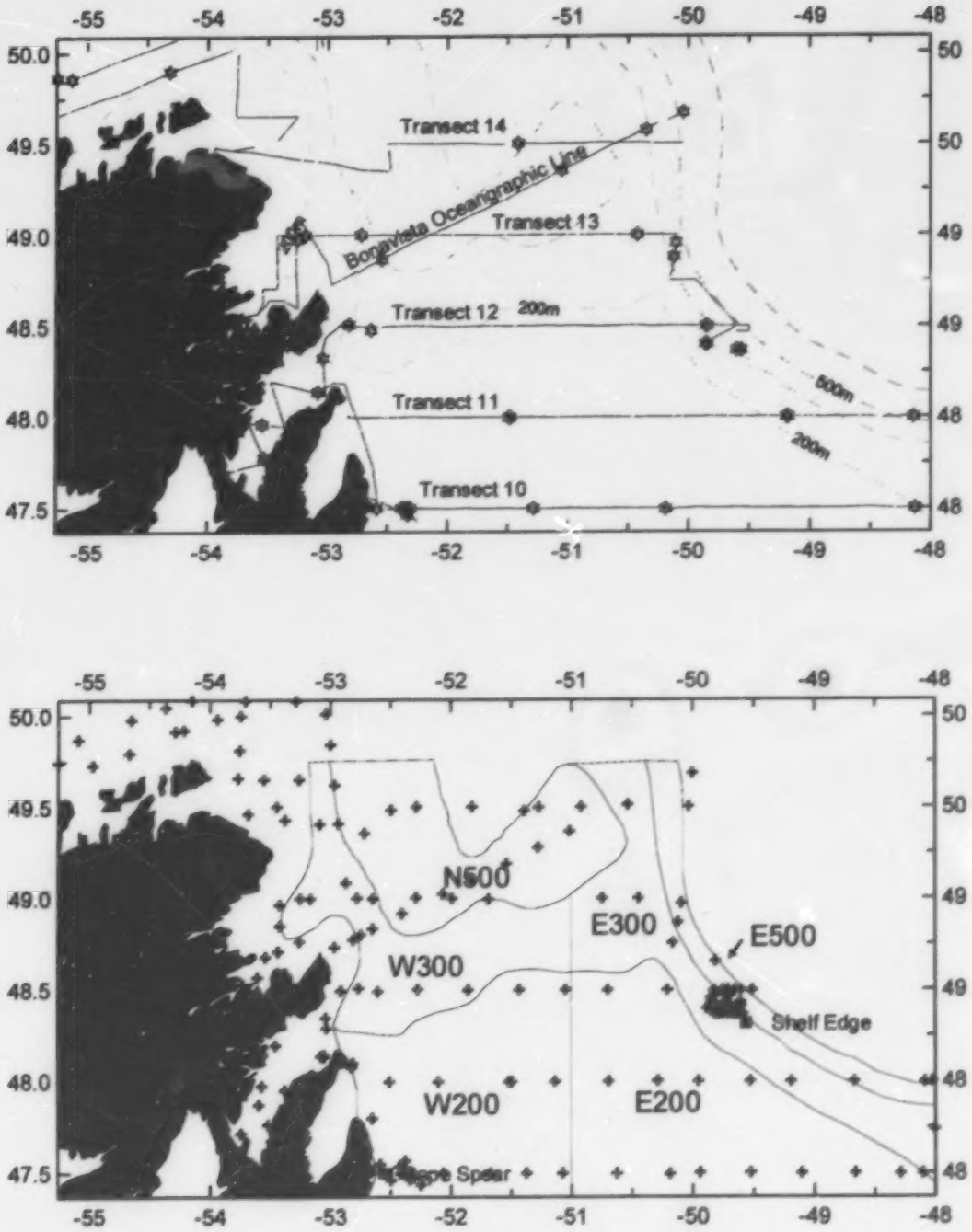


Figure 1. Map of North Eastern Newfoundland shelf showing in the upper panel: survey lines (solid), depth contours (dashed) and set locations (stars); and in the lower panel: meso-scale study sites (grey squares), stratum boundaries (solid lines) and XBT/CTD locations (crosses).

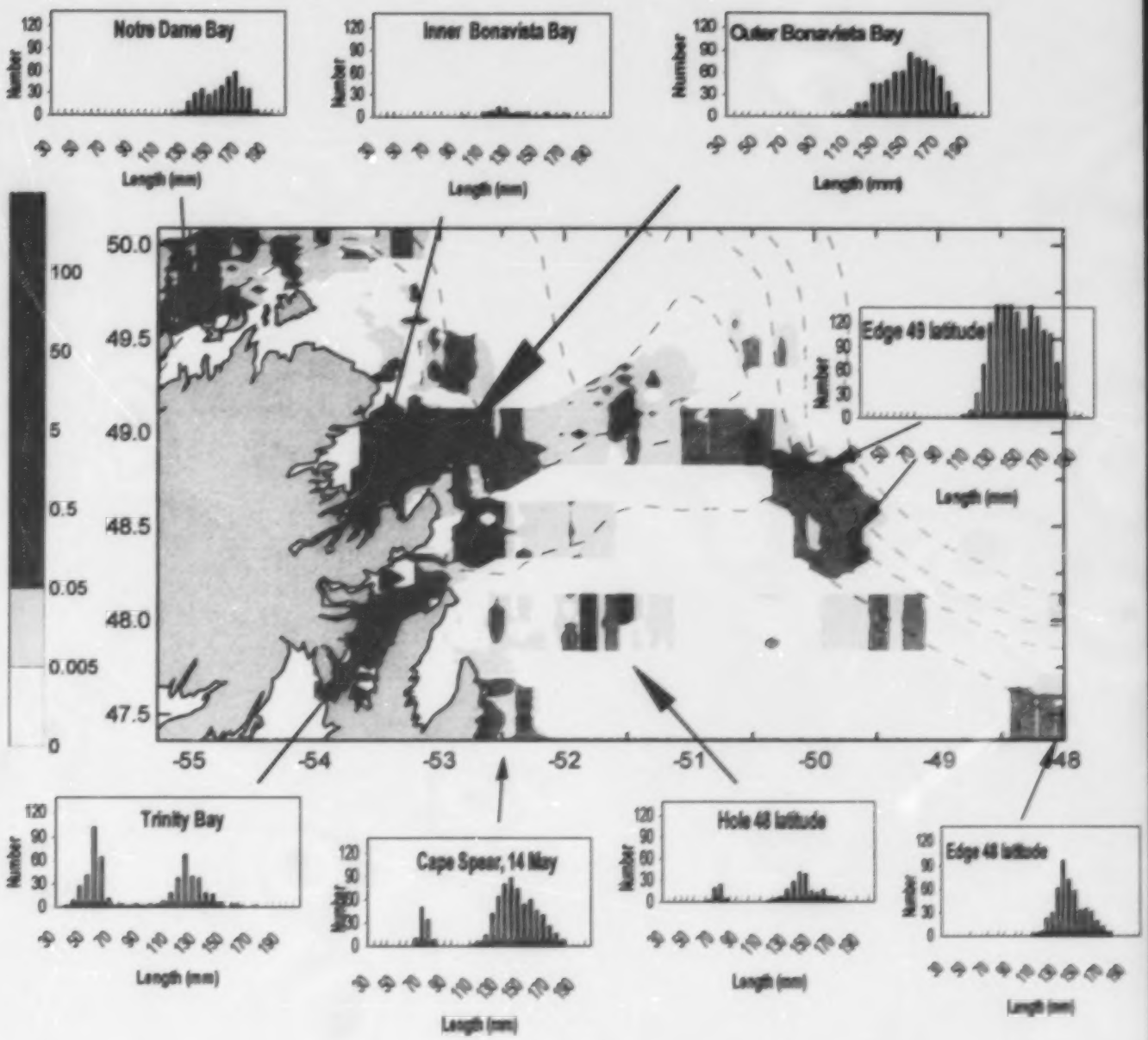


Figure 2. Northeastern Newfoundland shelf showing depth contours (dashed lines) and capelin densities (n/m2) (filled contours) from acoustic survey in May 1999. Pooled length frequencies of capelin caught in IYGPT and/or Campelen trawls are shown for each area of capelin concentration. Empty bars on length frequency plots indicate immature fish component, solid bars mature.

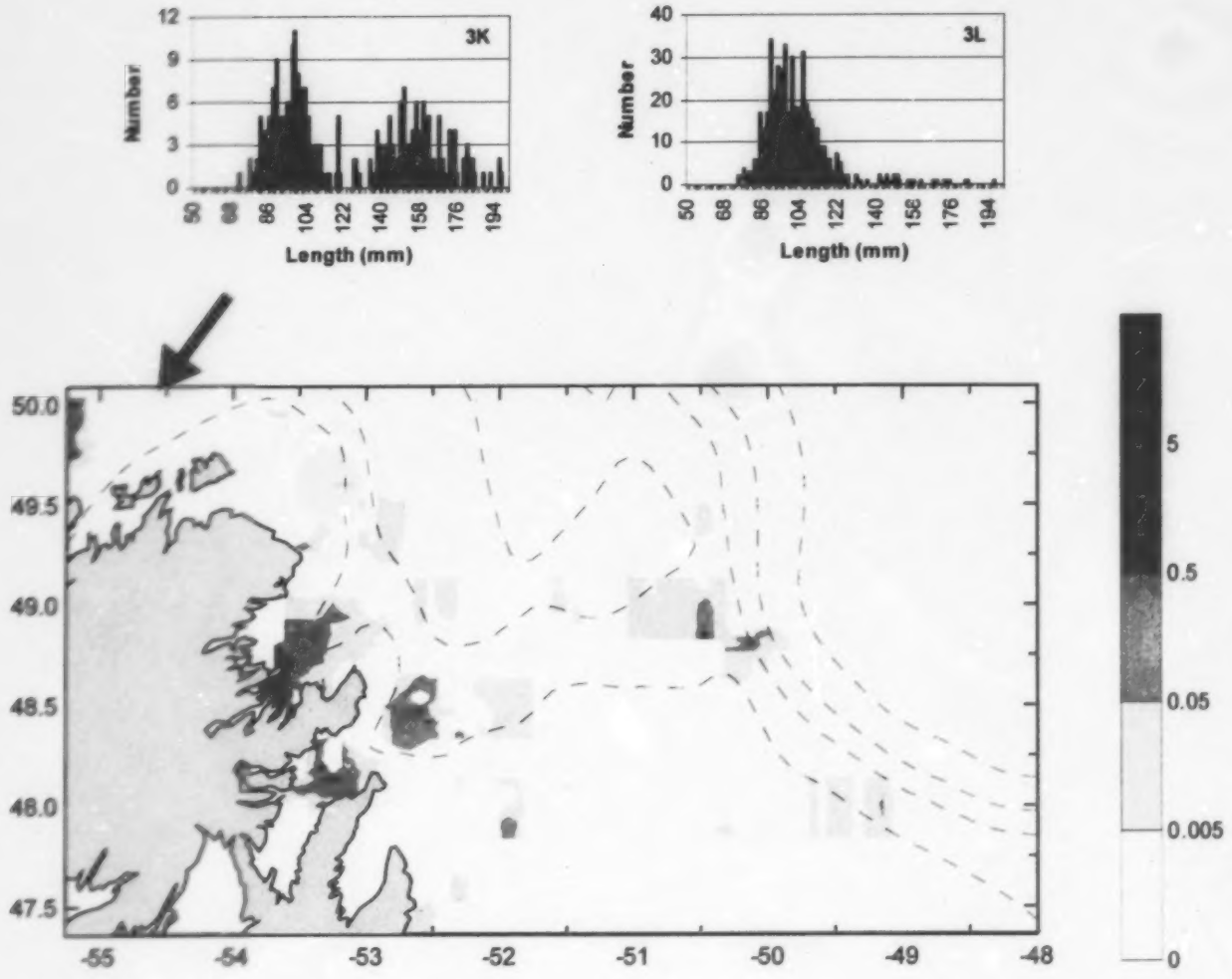


Figure 3. Northeastern shelf of Newfoundland showing depth contours (dashed lines) and arctic cod densities (n/m^2) (filled contours) as recorded during an acoustic survey in May 1999. Pooled length frequencies of arctic cod caught in IYGPT and/or Campelen trawls are shown for each area of concentration.

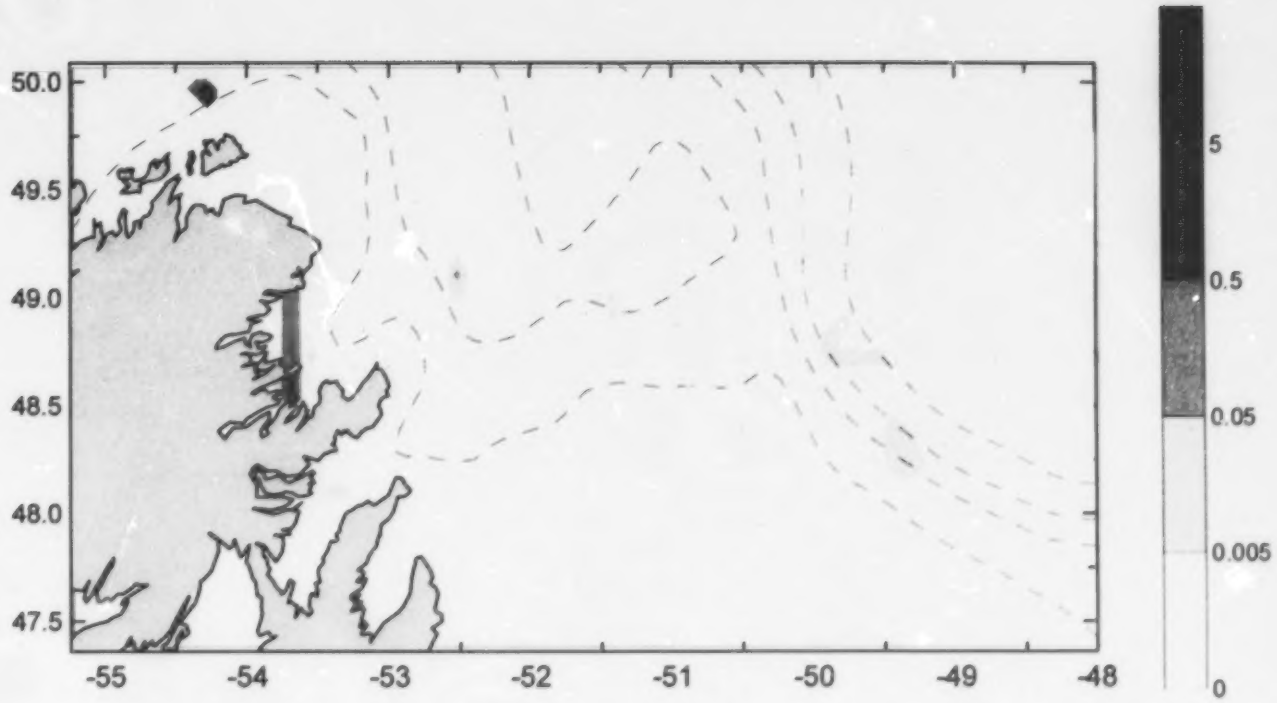


Figure 4. Northeastern shelf of Newfoundland showing depth contours (dashed lines) and Atlantic cod densities (n/m^2) (filled contours) from an acoustic survey in May 1999.

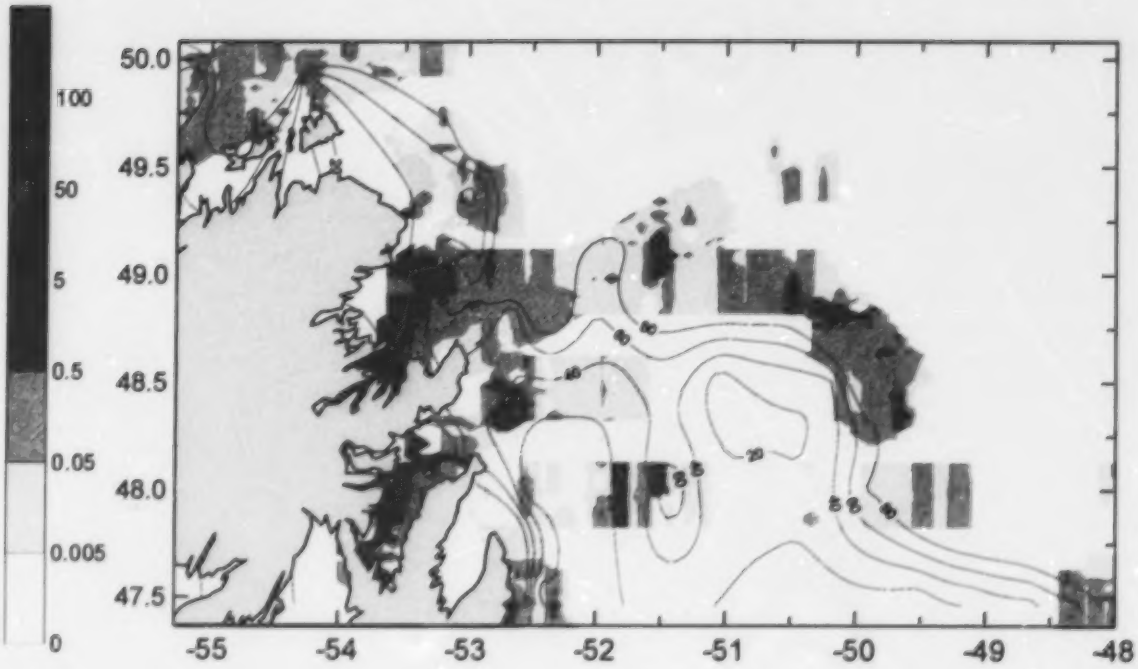


Figure 5. Height (m) of water consecutive to bottom with temperatures above 0 °C (line contours) and capelin density (n/m2) (filled contours), as recorded during an acoustic survey in May 1999.

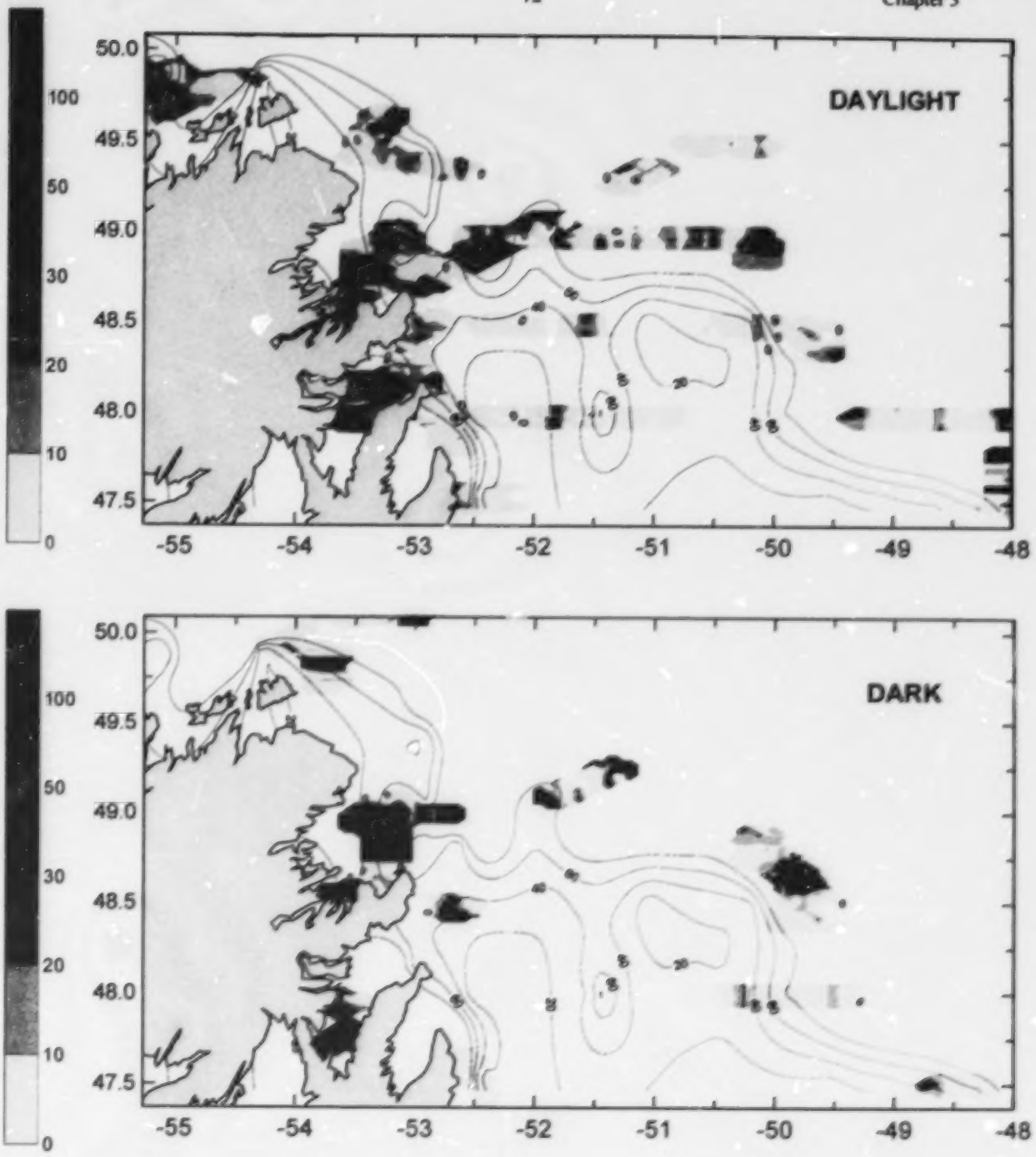


Figure 6. Height (m) of water consecutive to bottom with temperatures above 0 °C (line contours) and height off bottom (m) of peak capelin density (filled contours) during daylight hours (upper panel) and night (lower), May 1999.

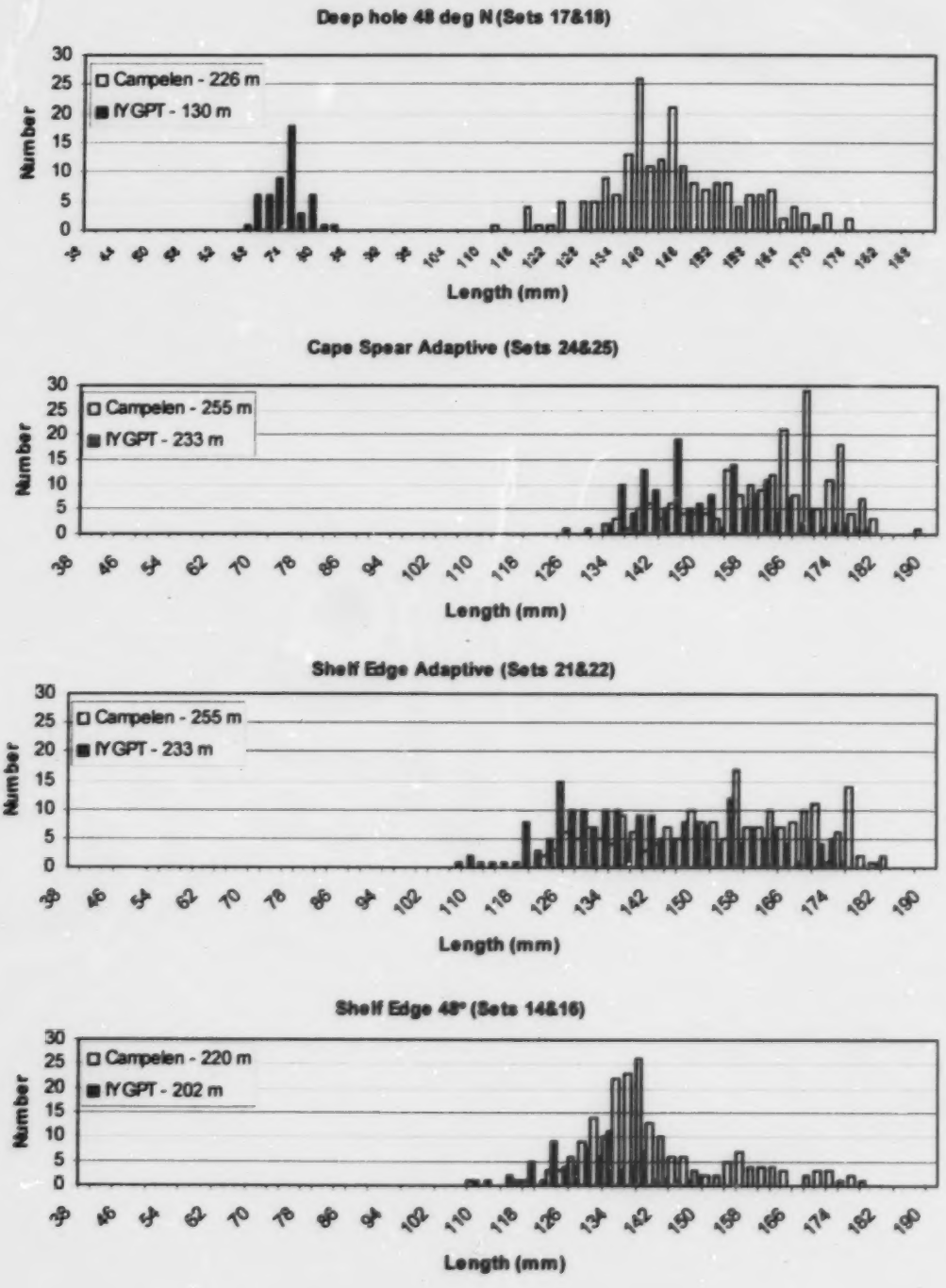


Figure 7. Comparative length frequencies of capelin caught in Campelen and IYGPT trawls fished over the same area during various portions of the May 1999 acoustic survey.

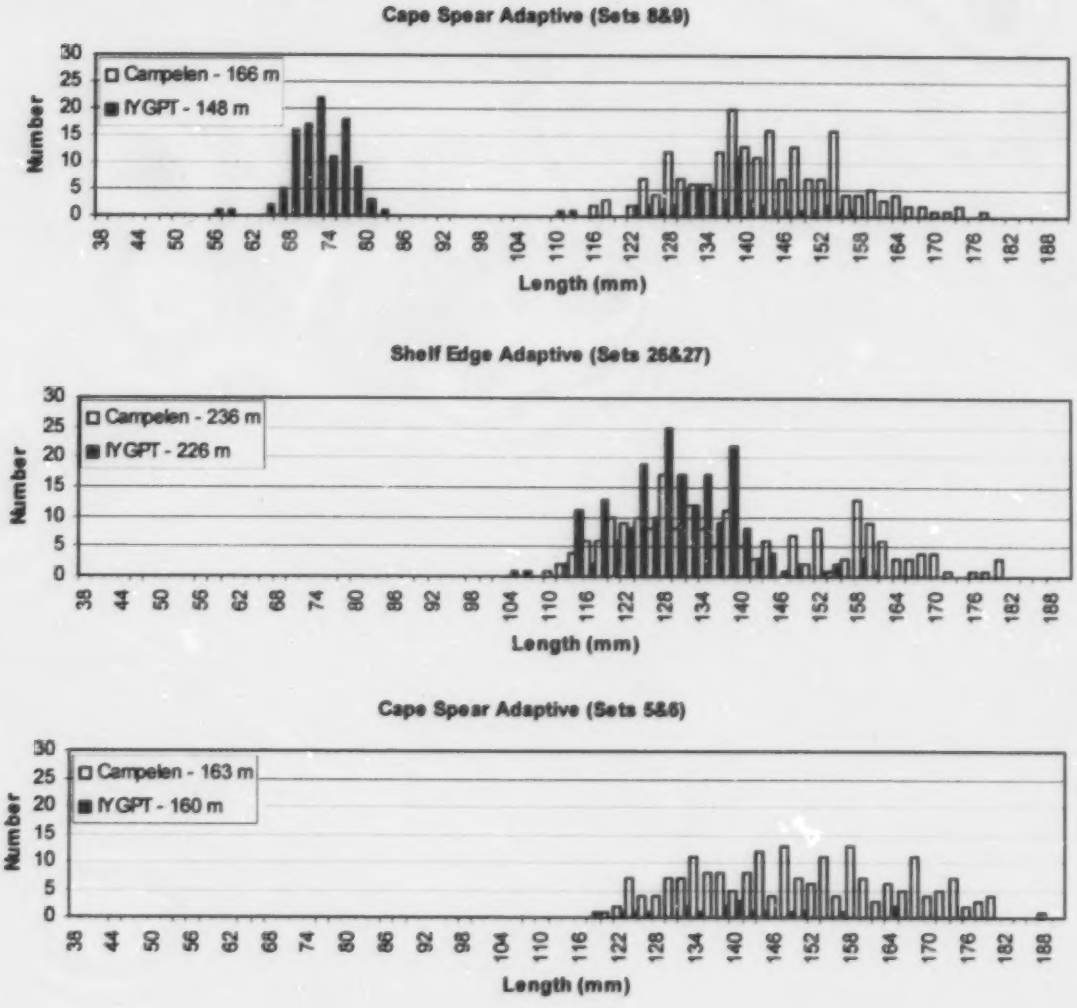


Figure 7. Continued.

Appendix 1. EchoSounder characteristics, calibration parameters, acquisition software and settings for capelin acoustic survey, May 1999.

Item	Type or setting
EchoSounder	Simrad EK500
Transducers	38 kHz and 120 kHz
38 kHz	
Transducer depth	6.00 m
Transducer type	ES38B
Absorption coefficient	10 dB/km
Pulse length	1 ms
Band width	3.8 kHz
2-way beam angle	-20.9 dB
Sv transducer gain	26.00 dB
TS transducer gain	25.82 dB
Angle sensitivity along	21.9
Angle sensitivity athwart	21.9
3 dB beamwidth along	7.0 deg
3 dB beamwidth athwart	7.0 deg
Alongship offset	-0.13
Athwartship offset	-0.15
120 kHz	
Transducer depth	5.00 m
Transducer type	ES120-7
Absorption coefficient	38 dB/km
Pulse length	0.3 ms
Band width	12 kHz
2-way beam angle	-20.6 dB
Sv transducer gain	23.00 dB
TS transducer gain	23.22 dB
Angle sensitivity along	21.0
Angle sensitivity athwart	21.0
3 dB beamwidth along	7.7 deg
3 dB beamwidth athwart	7.7 deg
Alongship offset	-0.22
Athwartship offset	-0.32
Ping interval	1.5 sec
Bottom detect minimum level	- 48 dB
Log mode	Time
Time interval	900 sec
Sample range	500 m
Sound speed (constant)	1460 m/sec

Appendix 1. (Continued).

Item	Type or setting
Acquisition sources	EK Ethernet and serial port output.
Ethernet output (primary data source):	
Acquisition software	CH1 Ver 2.00
Data format	HAC
TVT offset (Sv threshold)	-100 dB
Surface blanking range	0 m
Sample data	Ping based Sv samples
Serial port output (secondary data source):	
Acquisition software	HyperTerminal
Data format	ASCII
Parameters collected	Integration (s_A) and TS distribution tables by layer
Log mode	Time
Time interval	900 seconds
Depth range of layers	11-375 m
Number of surface referenced layers	8
Layer structure	Consecutive, no overlap
Layer height (layers 1-8) in meters.	14, 50, 50, 50, 50, 50, 50, 50

Appendix 2. Post acquisition echogram editing and integration settings and techniques and fish density calculation procedures.

Item	Type or setting
Editing and integration software	CH2 Versions 1.0 and 1.08
Editing and integration Sv threshold	- 85 dB
Species classifications	capelin, capelin mix, possibly capelin, cod, clung to bottom See explanation below
Elementary distance sampling unit	100 m
Layer structure	
Surface referenced layers	6 m-16 m, 16-20, 20-30, 30-40 ....490-500 m layers from 6 m to 500 m
Bottom referenced layers	0 m - 3.5 m, 3.5-8.5, 8.5-13.5, 13.5-18.5,18.5-23.5 m
Percent good data for integration	10 %
Bottom editing	Manually redrawn as required. See criteria below.
Standard Editing palette	Min= -65, Max = -30, Offset=-0.1, Span=0.8, Exponent = 2

Editing Procedures and Protocols:

1/ Entire echogram was viewed on one screen in surface lock mode.
2/ Sv Threshold ("TVT") was applied at start of file.
3/ Echogram was zoomed into 1 km sections (horizontal distance), full water depth.
4/ Pings of unusually high or low amplitude (as compared with their neighbours) were selected using the "select whole pings" tool and classified as "bad data". High amplitude pings were generally only present during trawling and were thought to be the result of interference from Scanmar (trawl) sensors or prop noise. Low amplitude sections resulted from attenuation caused by bubbles at the transducer face, commonly found in rough weather only.
5/ Display mode was then changed to bottom lock and bottom zoomed in on stretches 20-50 m deep * 1 km long. Bottom was redrawn using the "manual bottom" tool in areas where bottom appeared improperly placed. Criteria used to decide when bottom was to be redrawn included:

a) Sv amplitude (Sv > -50 dB were considered suspect);
b) Signal duration and height. Protrusions apparent in fewer pings that expected or less than a footprint depth in height were removed The minimum number of pings expected off a 'real' stationary target was calculated roughly as: Expected no. pings = Footprint diameter / Ping interval*speed, where footprint diameter is in meters, ping interval in seconds and speed in m/sec. Footprint diameter for the 7 degree beam angle is was estimated as

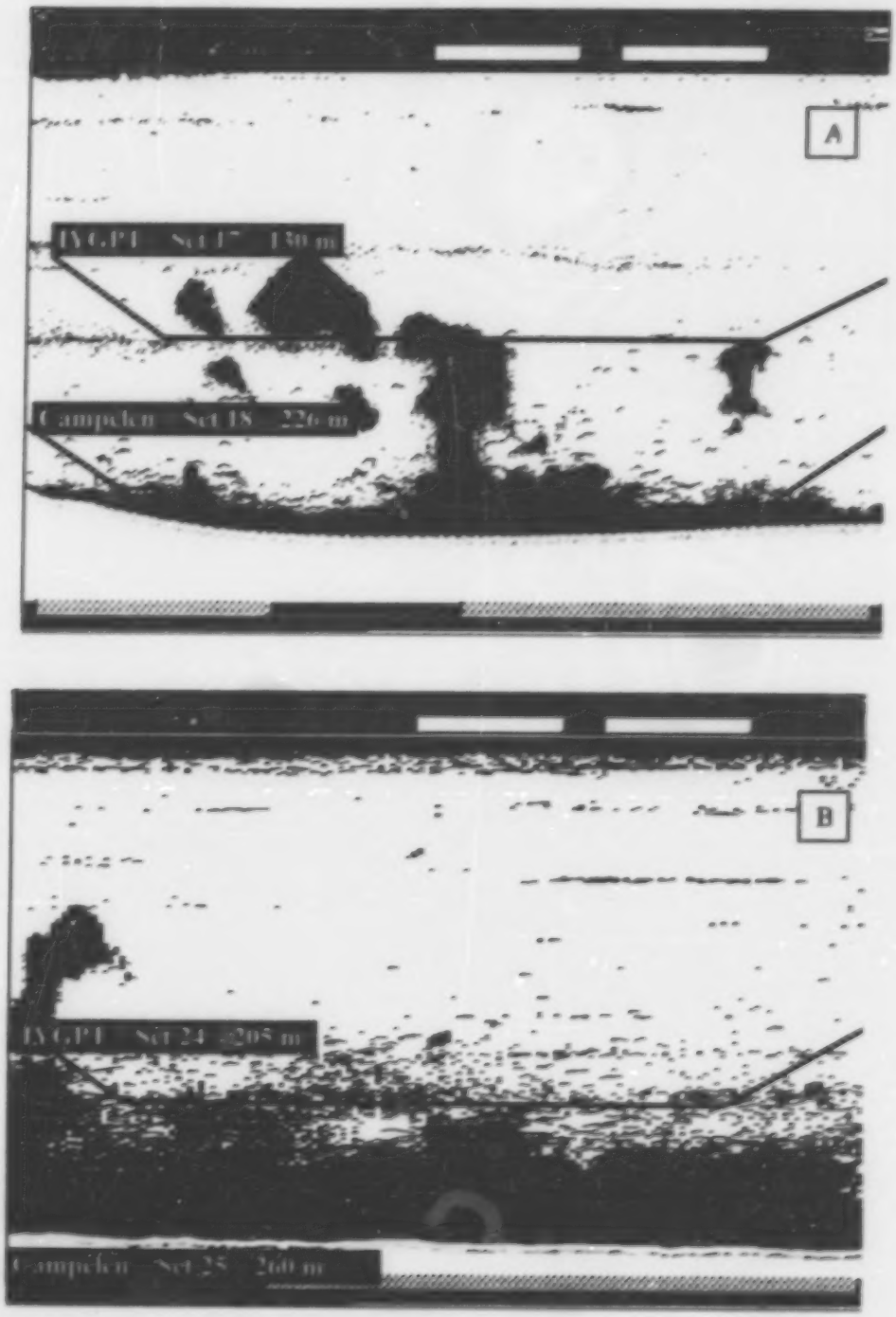
approximately 1/10 depth. Example: For a ping interval of 1.5, speed of 10 kts and 400m depth the expected number of pings per object is 5.

c) High amplitude samples were also removed when present on steep slopes. High amplitude marks on slopes were considered particularly questionable when there were no other fish marks in the vicinity.

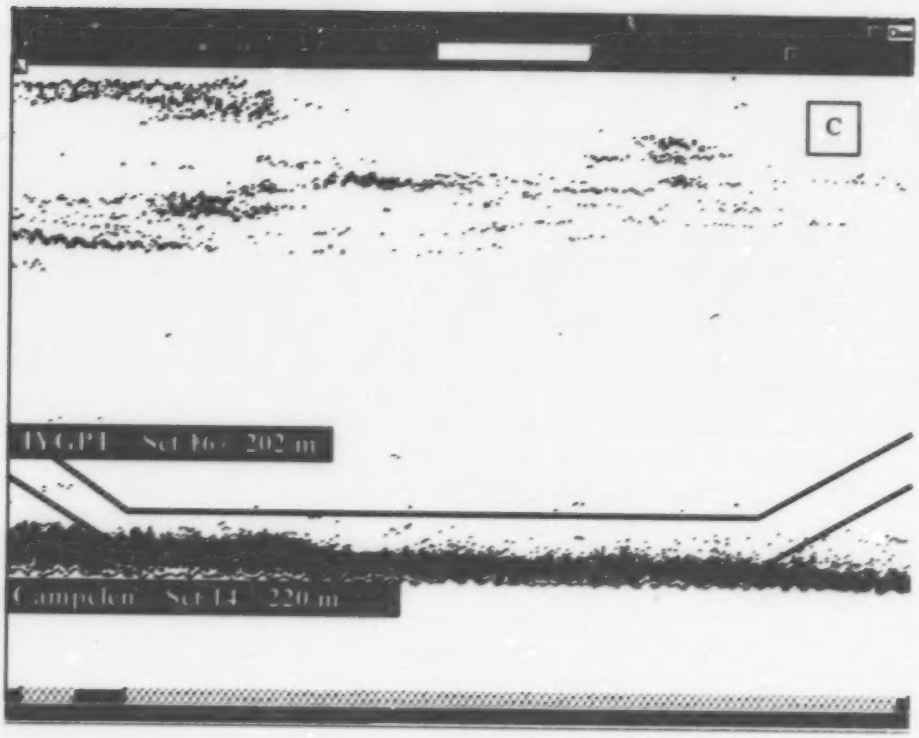
d) In cases where high amplitude samples existed consecutive to the bottom, but cases a-c did not apply, trends in Sv amplitude were examined under an increased level of zoom. If protrusions had a Sv amplitude pattern which consistently increased with depth it was considered that they could not be unambiguously called fish. Consequently a conservative approach was taken where these sections were was put in a separate classification called "clung to bottom" and not allowed to overlap with fish classifications. However, in cases where the Sv was high at the shallow end of a continuous section of samples, lower in the middle and higher again at the deepest portion, part of the protrusion was considered to be fish. In these cases bottom was redrawn directly above the first occurrence of samples with Sv values of –48 dB located in the water immediately above the point of peak amplitude.

6/ Echogram was again displayed in surface lock mode where all classifications performed. Fish marks were classified as possibly capelin, capelin, capelin mix or cod. Generally, rectangle or the below line tool were used for capelin and capelin mix calssifications, ellipse tool for cod, and the below line tool for 'clung to bottom'. All classes were spatially discrete except capelin mix and cod which always overlapped; cod were never classed outside of a 'capelin mix'.

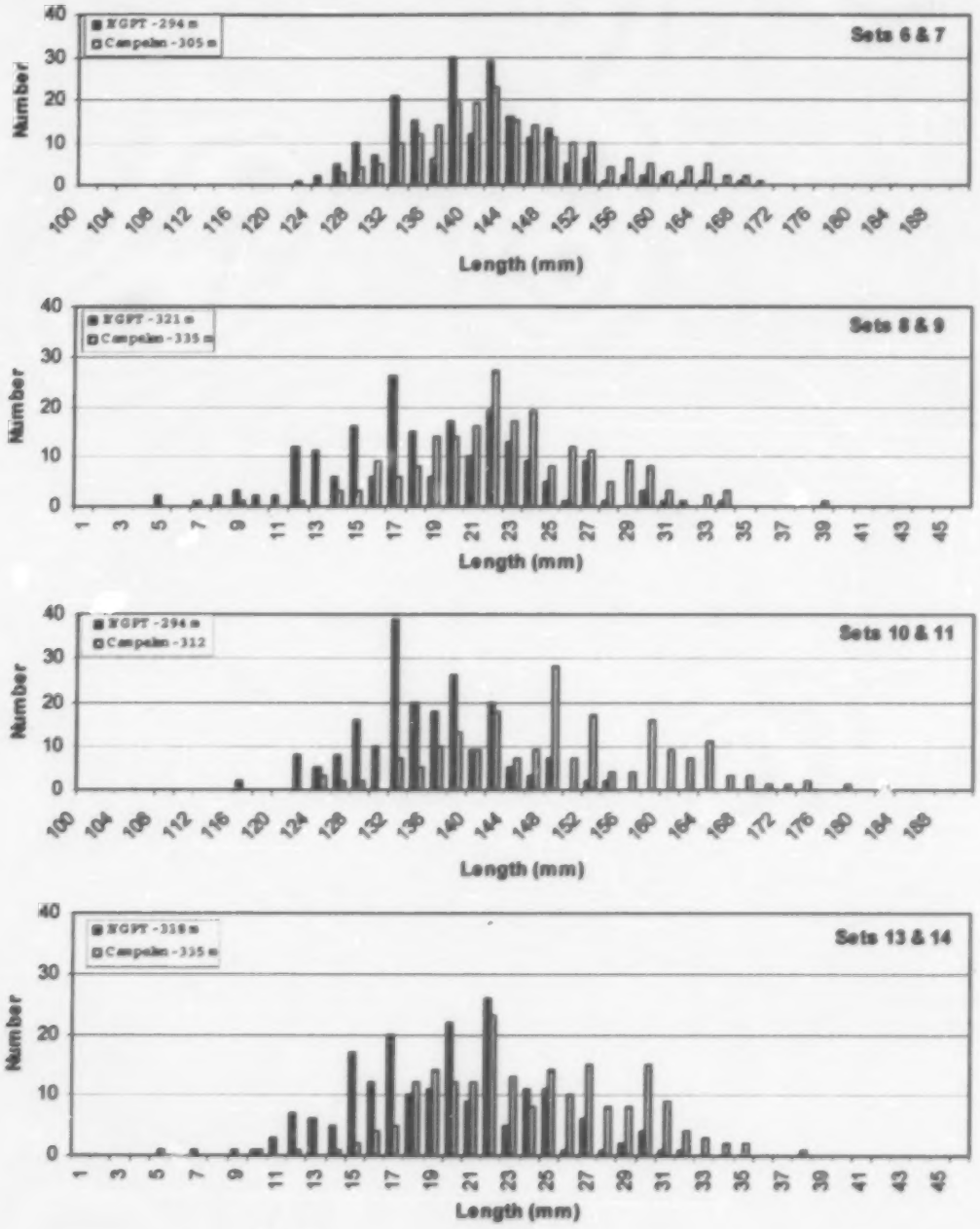
7/ File was saved as an edited HAC file and integration performed.



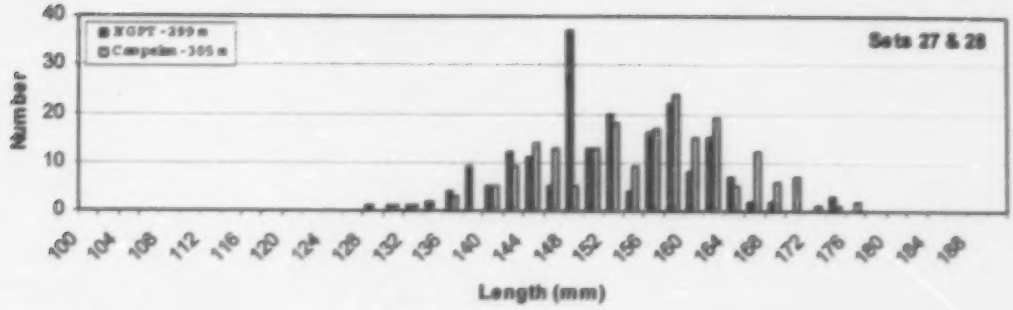
Appendix 3. Echograms showing capelin backscatter distribution and trawl paths (grey lines) at three (a-c) offshore comparative trawling sites sampled during May 1999.

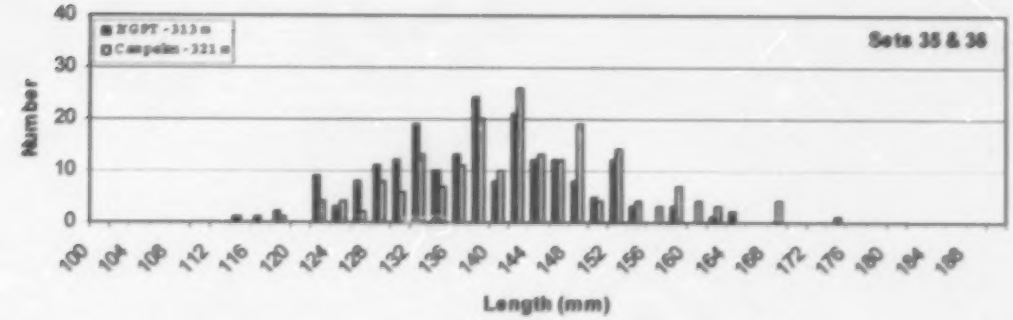


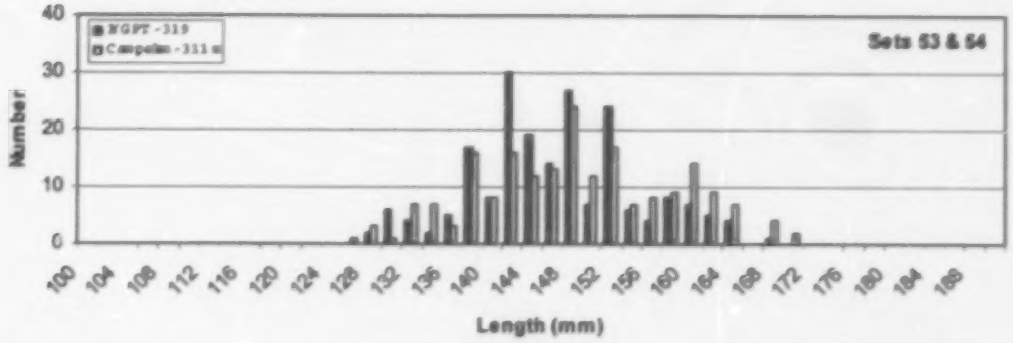
Appendix 3 - Continued.



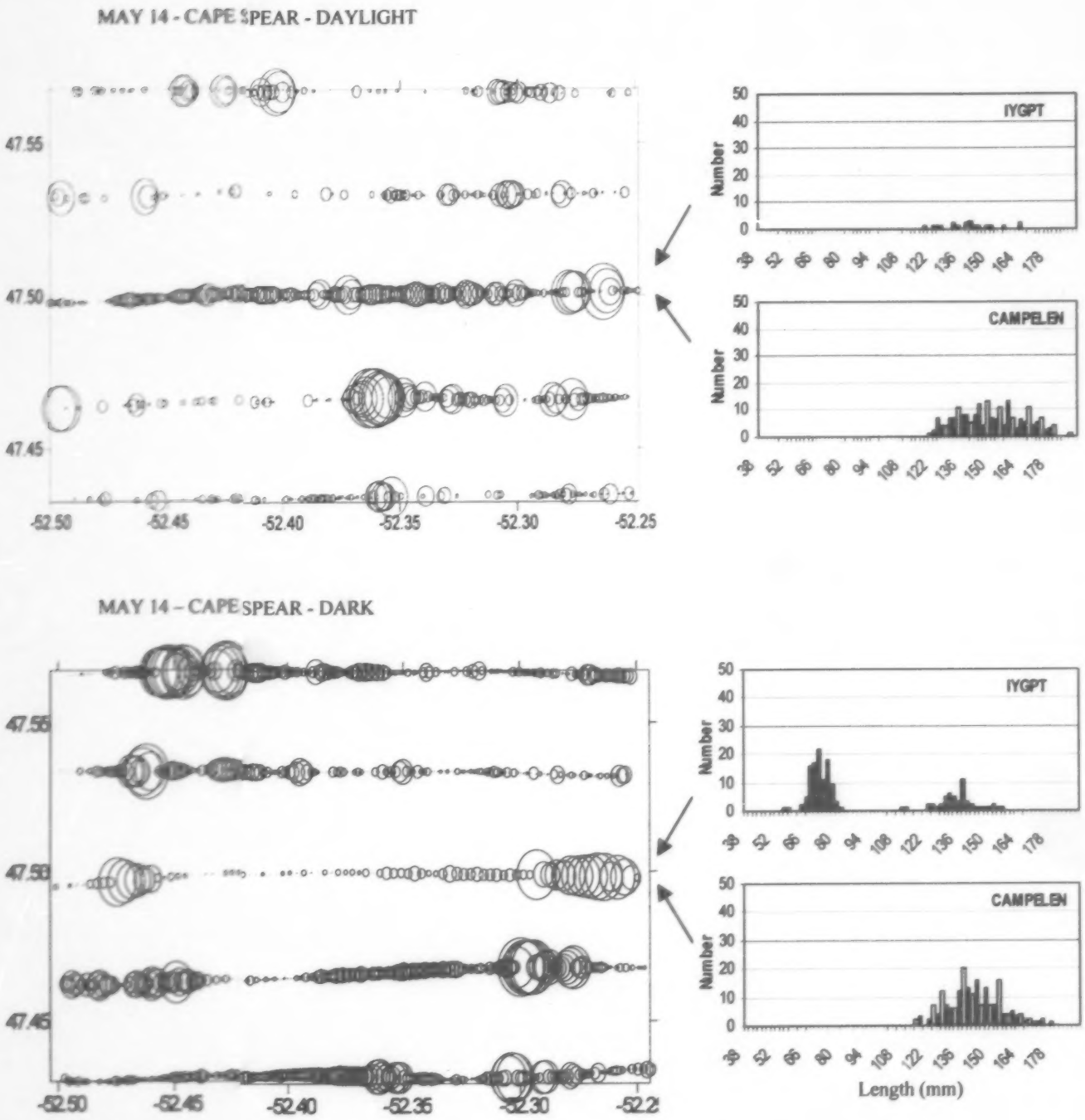
Appendix 4. Capelin length frequencies from comparative tows of IYGPT and Campelen trawls conducted in offshore 3K, fall 1995.



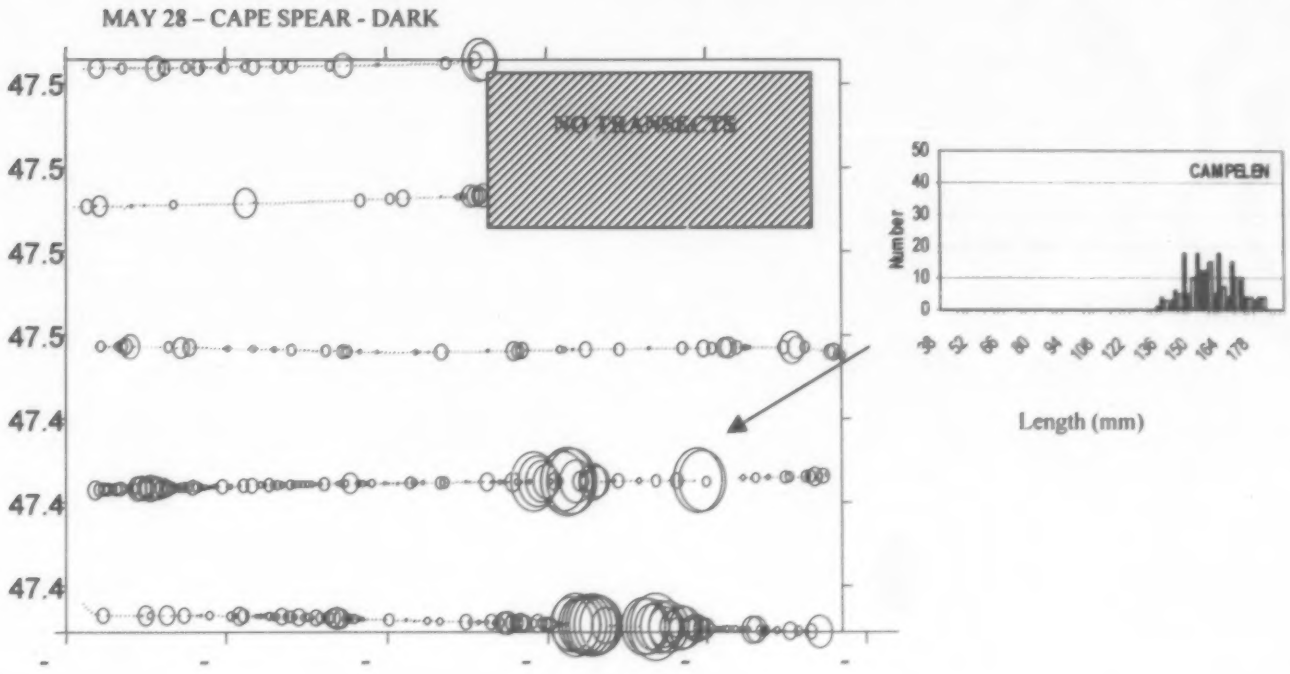




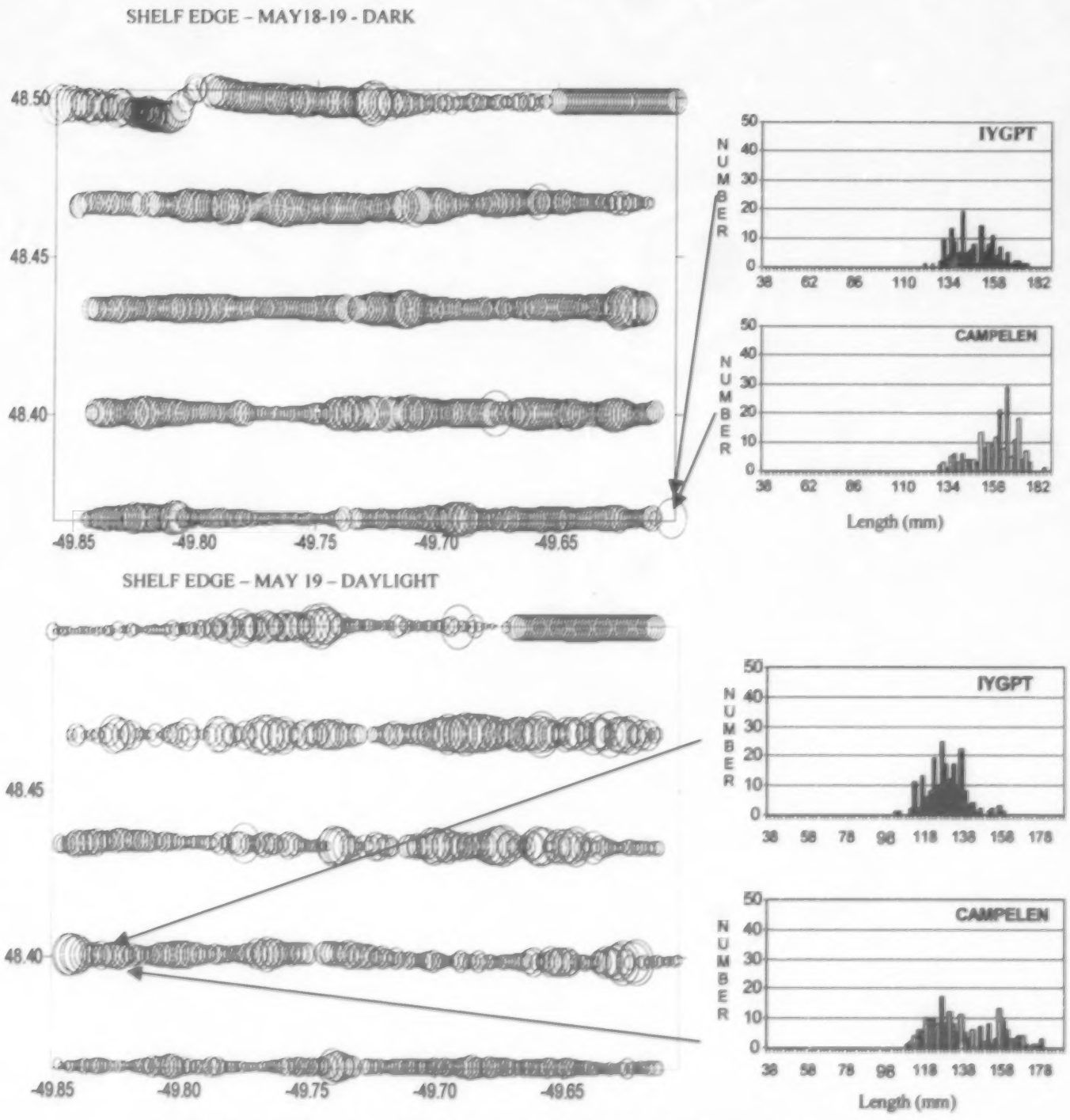
Appendix 4. - Continued



Appendix 5a. Expanding symbol plot showing logged capelin backscatter area distribution (dB) along the five transects of the meso-scale study site at Cape Spear, May 1999. Adjacent graphs contain length frequency distributions of capelin sampled from each site by trawling.



Appendix 5a (continued).



Appendix 5b. Expanding symbol plot showing logged capelin backscatter area distribution (dB) along the five transects of the meso-scale study site at the Shelf Edge, May 1999. Adjacent graphs contain length frequency distributions of capelin sampled from each site by trawling.

Spawning and Early Development of Capelin (Mallotus villosus) at Bellevue Beach, Trinity Bay in 1999

by

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Introduction

In 1990 we began to monitor spawning times, egg deposition and development, larval emergence and various environmental variables (e.g. sunlight hours, wind direction and speed, air temperature, water temperature, precipitation, beach sediment temperatures, beach disturbance) on two capelin spawning beaches located at Arnold's Cove in Div. 3Ps and at Bellevue Beach in Div. 3L (Fig. 1). The number of sites was expanded in 1991 to include five additional beaches at Chapels Cove, Eastport, Cape Freels, Twillingate, and Hampden in Div. 3KL (Fig. 1). In 1995 Chapels Cove and Bellevue Beach were sampled. Information from these sites can be found in Nakashima and Winters (1997). Since 1996 Bellevue Beach has been the only monitored site. In this report we present information on age, length, and weight of spawners, spawning times, egg densities, and pre-emergent and emergent larval estimates from Bellevue Beach, Trinity Bay.

Materials and Methods

Adult Samples

Random samples of 25 males and 25 females were collected whenever significant spawning had taken place. Random samples were also collected from a capelin trap located nearby at Rantem. Fish were measured for length and weight and otoliths removed for age determination.

Egg and Larval Sampling

During low tide conditions, egg samples in beach sediments were collected once every 48 hrs until eggs were no longer on the beach (<500 eggs per sample) and the numbers of pre-emergent larvae had declined. Nine samples subdivided into three samples per tidal zone (low tide, mid tide, high tide) were collected each time. A steel sediment corer (6.5 cm internal diameter) was used to extract each sample as described in Nakashima and Slaney (1993). Samples were preserved in 4% formalin and seawater solution buffered with sodium borate. To separate eggs from sediments, samples were immersed in 2% KOH solution for 24 hrs. To estimate pre-emergent larvae in beach cores larvae were sorted from eggs and counted. To estimate egg abundance, eggs were counted by subsampling with a whirling vessel (Nakashima 1987).

At each sampling site, a minimum of 50 eggs were placed in Stockard's Solution (Bonnet 1939) to fix and clear the eggs. Stages I-II (eggs from fertilization to the formation of the blastula) accounts for egg development up to the first 36 hrs at 7.2°C (Fridgeirsson 1976).

Newly emerging larvae were collected in the intertidal zone at high tide conditions generally twice a day. A 165 um plankton net was towed for 40 m parallel to the beach, rinsed, and the contents preserved in 4% formalin and seawater solution buffered with sodium borate. Two tows were conducted when emergence was peaking, otherwise only one tow was collected. Larval density was expressed as larvae per m^3.

Trapezoidal Integration

Total annual production of eggs and pre-emergent larvae were estimated by interpolating between point estimates applying trapezoidal integration. The seasonal estimate is:

$$\sum (t_n - t_{n-1}) \tfrac{1}{2} [X(t_n) + X(t_{n-1})]$$

where t is the julian day, n is the number of sampling days, and X(t) is the number of eggs or larvae on day t.

F2

Egg and Larval Densities

The ratio of Stage I-II eggs to total eggs in the Stockard's sample was used to estimate the number of Stage I-II eggs occurring in each beach core sample assuming that these eggs had been deposited recently on the beach. The daily average density of stages I-II eggs in all cores per tidal zone on a given beach was then estimated. An average beach density was assumed to be the mean of the three tidal zones. Total egg density of stages I-II eggs per unit area was estimated using the trapezoidal integration method.

The daily average density of pre-emergent larvae in all cores per tidal zone was estimated. An average density was assumed to be the mean of the three tidal zones. Total pre-emergent larval density was estimated using the trapezoidal integration method, as well.

The daily average density of emergent larvae was assumed to be the mean of the two high tide estimates. Total larval density per m^3 was then estimated using the trapezoidal integration method.

Results and Discussion

Spawner Characteristics

Age compositions of spawning fish from 1990 to 1999 were dominated by age 3 fish in all years, except 1992 when age 4's were most abundant (Table 1). Our age composition data show that the 1999 spawning population consisted mainly of the 1996 yearclass (73%) followed by the 1997 yearclass (17%). The proportion of age 2 fish is considerably higher for females than for males (Table 1). The 1995 yearclass was proportionally low in abundance. This is the second year that age 4 fish were scarce, especially so for females in 1999.

Mean weights and lengths of females and males and the samples in general are presented in Table 2. Average size appears to be increasing.

Spawning Time

In 1999 spawning began on June 28, which was marginally earlier than in 1998 (Table 3), and all eggs were deposited by July 12(Fig. 2). Unlike other years that the beach has been monitored, there was only one major spawning run. Consequently the time of egg deposition on Bellevue Beach was protracted (Table 3).

Egg Density and Development

One major spawning mode was observed in early July (July 4-8) (Fig. 2). Egg densities on Bellevue Beach were one of the highest estimated in the series (Table 3). This suggests that for this area, the mature population spawning on the beach sediment was abundant relative to other years in the 1990s.

Observations during the spawning period indicated that strong wave action near the end of the spawning period washed many of the eggs high up on the beach. When evaluating eggs for development staging, we noticed a high proportion of opaque and abnormal eggs in the samples, similar to 1998 (Nakashima and Slaney 1999). Also many of the eggs that began development, failed to survive beyond stage IV, 4-6 days after fertilization.

Pre-emergent Larval Estimates

The majority of pre-emergent larvae observed in beach sediments at Bellevue Beach in 1999 occurred July 20-22 (Fig.3) which was 11 days earlier than the first major sign of pre-emergent larvae in 1998 (Nakashima and Slaney 1999: July 31-Aug. 4). The density of pre-emergent larvae was the lowest in the series and comparable to 1998(Table 3). This indicates that egg mortalities in beach sediments have been very high in 1998 and in 1999. The 1999 yearclass is one of the weakest produced from beach spawning at Bellevue Beach in the 1990s.

Emergent Larvae

Emergent larval densities were very low in 1999 with no strong peak as in other years. The highest amount released was on July 22 at night (Fig. 4). However, the actual amount was very low (8000/m^3) and the lack of multiple releases suggest larval production from Bellevue Beach sediments was very poor in 1999. Like the pre-emergent larvae, the results indicate the 1999 yearclass is one of the weakest in the series, similar to the 1991 yearclass (Table 3).

Summary

The results indicate that there was a high mortality of eggs in Bellevue Beach sediments in 1999 resulting in low densities of pre-emergent larvae. This also affected the potential production of emergent larvae. Another contributor to low production was the presence of only one spawning episode. Despite the high egg deposition, the results suggest that having all the eggs deposited at once resulted in poor survival due to adverse conditions experienced during incubation in the sediments. Consequently the 1999 yearclass produced from Bellevue Beach was relatively weak.

Acknowledgements

Pelagic Fish Section staff and summer students collected the field data. Core and emergence samples were processed by C. Coady, J. Croft, and A. Powell. Special thanks to F. Teletchea, a coo-op student from St. Pierre et Miquelon, for field and laboratory assistance. R. Clarke, Chance Cove, collected capelin samples throughout the spawning season and performed frequent CTD casts. M. Y. Farrell assisted in the preparation of the manuscript.

References

Bonnet, D. D. 1939. Mortality of the cod egg in relation to temperature. Biol. Bull. 76: 428-441.

Fridgeirsson, E. 1976. Observations on spawning behaviour and embryonic development of the Icelandic capelin. Rit. Fiskideildar 5: 1-24.

Nakashima, B. S. 1987. Regional and temporal variations in fecundity of capelin in Newfoundland waters. Trans. Am. Fish. Soc. 116: 864-873.

Nakashima, B. S., and B. W. Slaney. 1993. Capelin (Mallotus villosus) egg deposition on fifteen spawning beaches in Conception Bay, Newfoundland in 1992. DFO Atl. Fish. Res. Doc. 93/7. 11 p.

Nakashima, B. S., and G. H. Winters. 1997. Egg and larval production from Bellevue Beach, Trinity Bay in 1996. pp. 74-83. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 97/29.

Nakashima, B. S. and B. W. Slaney. 1999. Spawning and early development of capelin (Mallotus villosus) from Bellevue Beach, Trinity Bay in 1998. pp. 71-82. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 99/206.

Table 1. Age composition by numbers for mature capelin from Bellevue Beach, Trinity Bay combined. In 1990 only females were sampled.

Sex	Year	Age 2	3	4	5	6	Sample size
M	1991	9.7	40.3	45.0	5.0	0	300
	1992	3.5	30.0	58.0	8.5	0	200
	1993	1.0	68.0	29.0	2.0	0	300
	1994	9.3	56.5	28.8	5.1	0.3	375
	1995	7.3	54.0	27.4	11.0	0.3	328
	1996	4.4	67.6	26.5	1.3	0.3	321
	1997	5.3	48.5	37.7	8.0	0.6	324
	1998	2.0	74.8	20.2	3.0	0	396
	1999	4.0	81.0	15.0	<.1	0	273
F	1990	4.9	49.8	42.1	3.2	0	247
	1991	15.1	45.8	31.5	7.1	0.4	238
	1992	10.0	37.0	44.0	8.5	0.5	200
	1993	11.0	70.0	17.3	1.7	0	300
	1994	17.9	49.9	24.3	7.7	0.3	375
	1995	24.5	55.0	12.7	7.9	0	229
	1996	14.2	61.3	21.8	2.1	0.7	289
	1997	14.5	49.4	26.2	9.3	0.6	324
	1998	26.6	56.1	14.4	3.0	0	369
	1999	32.0	65.0	3.0	0	0	253
Combined	1991	12.1	42.8	39.0	6.0	0.2	
	1992	6.8	33.5	51.0	8.5	0.3	
	1993	6.0	69.0	23.2	1.8	0	
	1994	13.6	53.2	26.5	6.4	0.3	
	1995	14.4	54.4	21.4	9.7	0.2	
	1996	9.0	64.6	24.3	1.6	0.5	
	1997	9.9	48.9	31.9	8.6	0.6	
	1998	13.9	65.8	17.4	3.0	0	
	1999	17.0	73.0	13.0	<.1	0	

Table 2. Mean weights (W in gms) and mean lengths (L in mm) of males, females and sexes combined from samples of spawners collected at Bellevue Beach.

Year	Males		Females		Sample	
	W	L	W	L	W	L
1990	-	-	24.9	160	-	-
1991	31.8	173	20.4	156	26.7	165
1992	25.2	165	17.2	150	21.2	158
1993	27.5	167	17.5	150	22.5	159
1994	26.0	167	18.6	153	22.3	160
1995	24.3	161	14.8	141	20.4	153
1996	28.2	169	18.5	154	23.6	162
1997	24.6	163	18.1	149	21.4	156
1998	25.5	165	16.5	149	21.2	157
1999	29.6	171	19.4	153	24.7	162

Table 3. Annual estimates derived from trapezoidal integration of egg deposition, pre-emergent larvae, and emergent larvae and range of spawning dates for Bellevue Beach, Trinity Bay.

Year	Egg deposition Stages I-II eggs ('000 eggs/core)	Pre-emergent Larvae ('000 larvae/core)	Emergent larvae ('000 larvae/m^3)	Spawning Dates (Julian Day)
1990	92.2	26.2	212.1	175-207
1991	242.2	9.0	60.5	185-234
1992	261.7	18.3	192.5	185-232
1993	337.6	27.1[a]	175.3[b]	182-242
1994	192.5	17.4	109.8	180-217
1995	153.8	20.9	140.1	192-218
1996	243.3	15.2	93.6	178-215
1997	263.5	21.5	-	191-224
1998	452.6	6.2	45.0	183-228
1999	374.4	4.2	38.9	181-195

[a] Adjusted to account for sampling stopped before all eggs had hatched. Unadjusted estimate was 17.2.

[b] Adjusted to account for sampling stopped before all larvae had emerged from sediments. Unadjusted estimate was 111.0.

Fig. 1. Sampling sites.

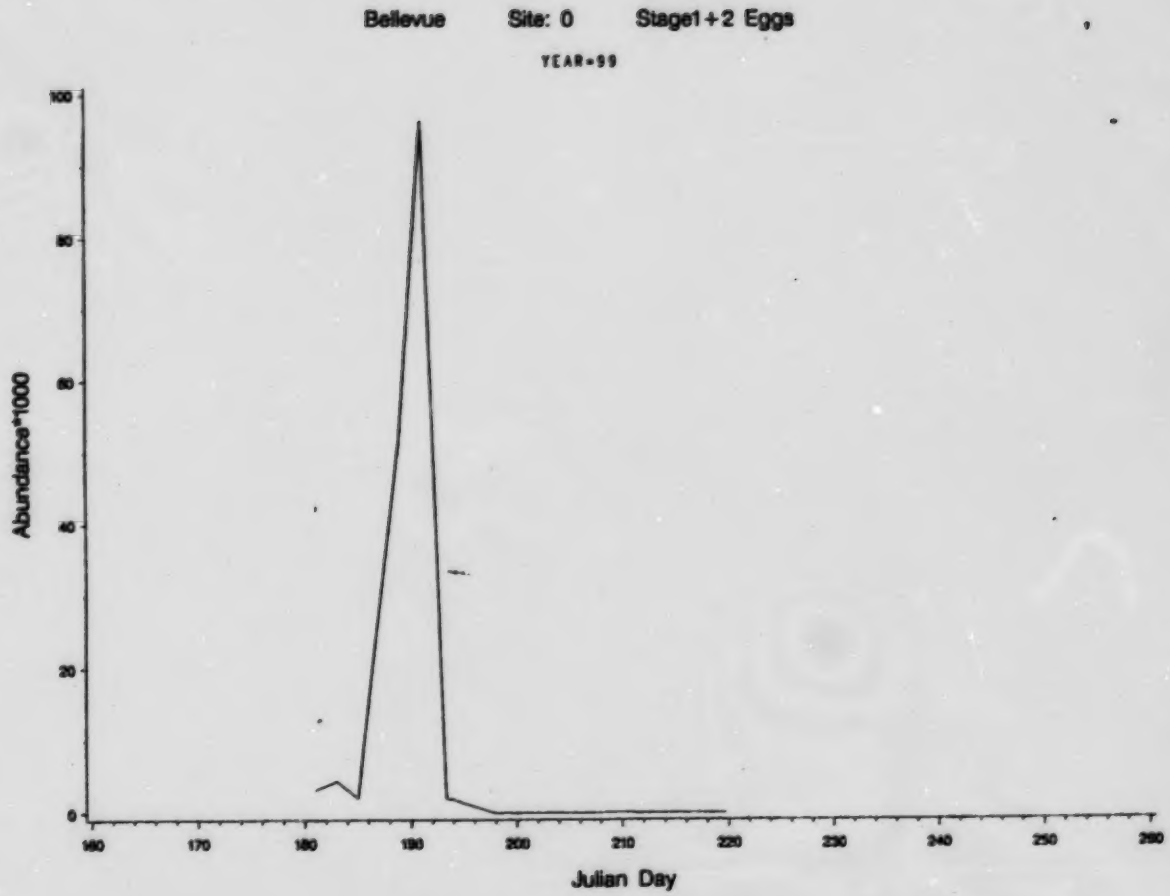

Fig. 2. Seasonal pattern in egg deposition on Bellevue Beach in 1999.

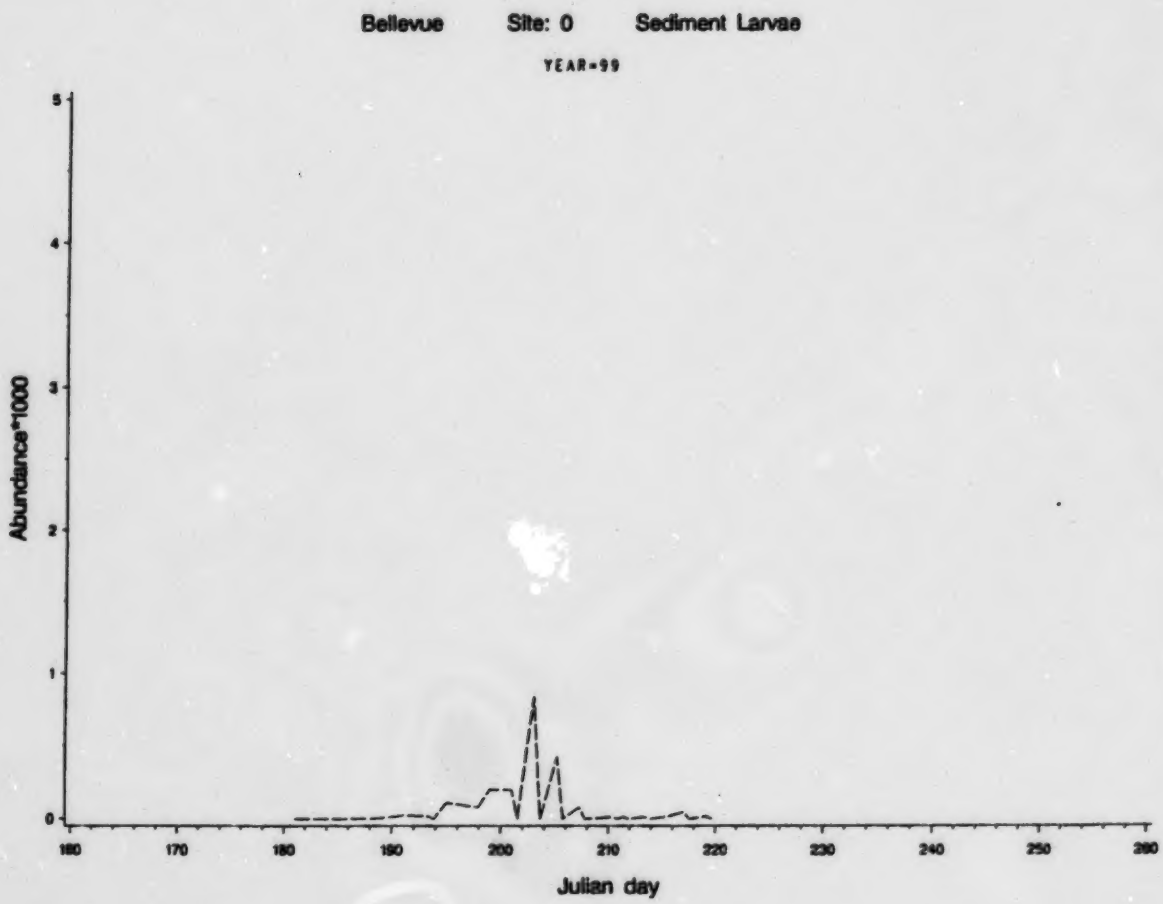

Fig. 3. Seasonal pattern in pre-emergent larvae in Bellevue Beach in 1999.

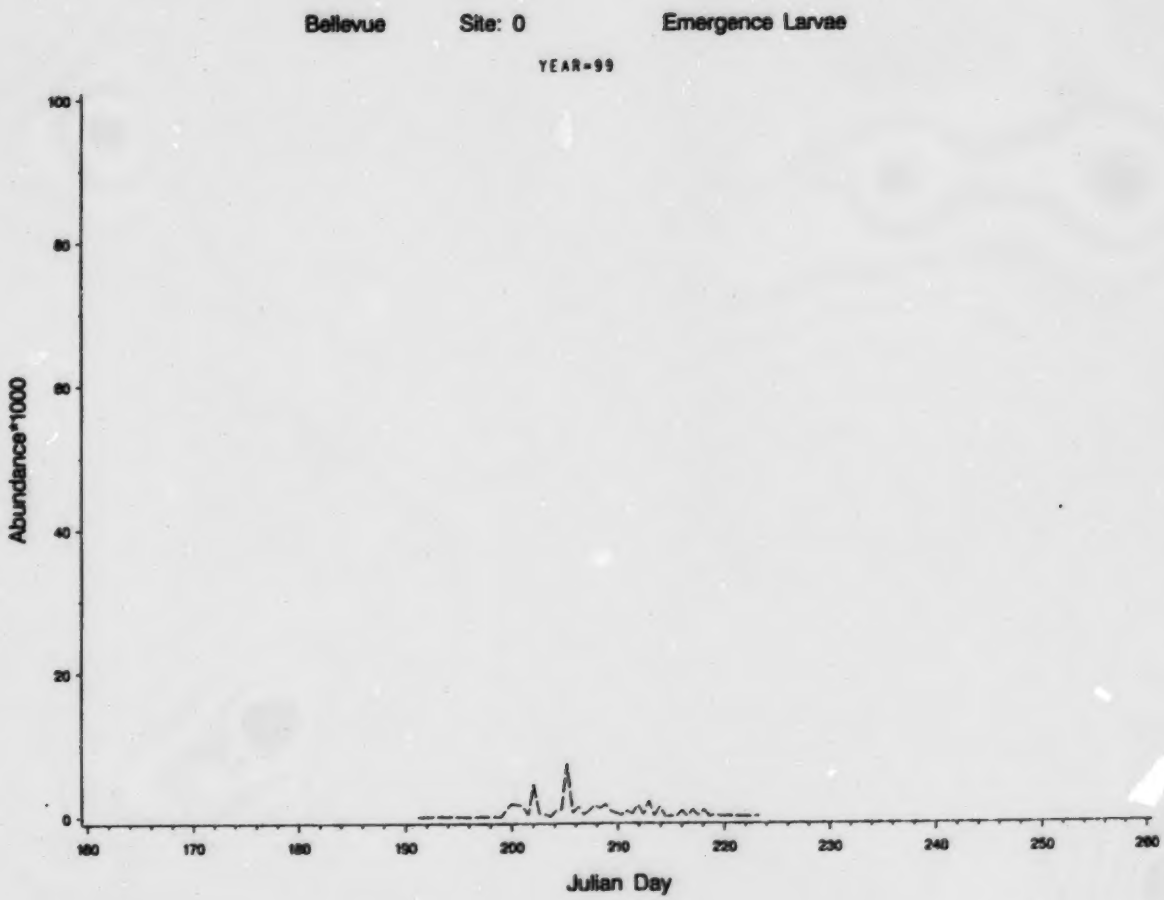

Fig. 4. Seasonal pattern in larval emergence from Bellevue Beach in 1999.

Results from a 1999 Field Study on: 1) the distribution and biomass of capelin, and 2) the classification of substrates at Bellevue, Trinity Bay

by

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Introduction

Bellevue Beach, Trinity Bay, is one of many important capelin spawning locations along the northeast coast of Newfoundland. The area has been the focus of inshore capelin research studies within the Newfoundland region for many years. It forms a part of the flight path of an aerial survey which has been conducted annually since 1982 to estimate the relative abundance of pre-spawning capelin (Anon. 1997). It has also been the site of an annual capelin egg and larval production study since 1990 (Anon. 1997). Results from these studies have been important as indices of abundance for capelin in the inshore area.

For the past three years, an additional component has been added to the research studies in the Bellevue area. In 1997, a preliminary acoustic survey was conducted to examine the distribution and biomass of pre-spawning capelin in the near coastal zone off Bellevue Beach. In 1998, this research was expanded to include daily acoustic surveys of a pre-selected area throughout the spawning season. A second component was added to map the densities of individual capelin schools detected by the aerial survey (Wheeler and Nakashima 1999). In 1999, daily acoustic surveys were again conducted through the spawning season. Underwater video was also used to classify bottom substrates within the survey area and to examine for the occurrence of off beach spawning.

This paper documents the results of the acoustic and underwater video research conducted during the 1999 field season. Daily density and biomass estimates are provided and these are compared with results from 1998. The results of the substrate classification are also presented.

Methods

1) Distribution and Biomass

Acoustic surveys in 1998 and 1999 were conducted from the 7 m vessel *Topaz* equipped with a BioSonics Model 105 sounder and a Femto Model 9001 acoustic data acquisition system. A 120 kHz single beam transducer was mounted in a V-fin towed body and was deployed at a depth of approximately 1 m abeam of the survey vessel.

This acoustic system is calibrated annually. The following parameters, from a calibration conducted in September 1999, were used in the analysis of the 1999 data:

Source Level / Receive Sensitivity	: 42.25 dB
Fixed Receiver Gain:	11.31 dB
TVG Gain:	20 log R
Attenuation Coefficient:	0.03470 dB/m
Pulse Length:	0.4 ms
Average Beam Factor:	-29.4 dB

Based upon preliminary acoustic surveys conducted in 1997, a survey area was defined in the coastal zone off Bellevue Beach (Figure 1). The survey area was 5.4 km^2 and included the area from Green Head in the northwest to 'The Gut' in the southeast. The inner boundary of the area was defined by the minimum navigable depth of the survey vessel (~3 m). The outer boundary was defined by the coastal distribution of capelin detected during the preliminary surveys in 1997, which, through much of the survey area, was approximately 1 km from the shoreline. The area was divided into five geographically based strata. Stratum 'E' was defined to be a subset of stratum 'D' and was designed to allow for more detailed acoustic sampling along Bellevue Beach.

A zig-zag survey through each stratum was deemed to be the most efficient survey design as it maximized acoustic sampling and minimized the time required to conduct each survey. Differential GPS and *Infonav* navigational software were used to ensure that the same transects were covered during each survey. A detailed log record was maintained during each survey of the area.

The acoustic data were subsequently edited using the Femto acoustic data editing system. Due to the irregular nature of the bottom topography throughout the survey area, a variable bottom removal algorithm was used. Only those concentrations considered to be capelin, based upon visual examination of the echograms, were included for analysis.

Acoustic back-scatter (m^2/sr) was converted to fish density (g/m^2) using a fixed target strength of -34 dB/g (Anon. 1997).

A single density estimate (g/m^2) was derived for each stratum based upon the series of zig-zags within the stratum. This was extrapolated to the stratum area to estimate stratum biomass. Strata estimates were summed to calculate total biomass for the survey area.

In each survey, the larger of the biomass estimates for strata 'D' and 'E', ie. overlapping strata, was used in calculating total biomass of the total area.

For the purpose of plotting capelin distributions, mean densities (g/m^2) were calculated per ten second interval along each transect.

2) Substrate Classification

An underwater video system was used in 1999 to classify bottom substrates and to examine for the occurrence of off beach spawning. The camera was attached to a tripod which when lowered to the ocean floor kept the camera at a fixed distance of 1 m from the bottom. Video images were calibrated using a metre stick placed beneath the tripod. Video data were viewed in real time on a monitor aboard the *Topaz*; data were also recorded to tape in Hi8 format.

Video data were recorded from 168 locations within the survey area (Figure 6). These sites were chosen systematically to map as much of the acoustic survey area as possible. The location of each sampling site was determined by differential GPS. The depth of the sampling sites was restricted to 20 m and less, ie. the length of the power cable on the video camera.

In addition to being able to identify substrate particle sizes, the video camera could distinguish the presence of capelin eggs on the substrate. However, as the resolution of the video images were insufficient to estimate egg densities, only the presence or absence of capelin eggs at each location was recorded.

The video data were analysed using *Mocha* image analysis software. A single video frame from each sampling site was digitized. A selection of ten substrate particles were measured from each digitized frame and mean particle size was calculated.

Results

1) Distribution and Biomass

A total of 10 acoustic surveys were conducted in the Bellevue survey area during the 1999 field season (Figures 2 and 3). Peak densities and biomass were detected during the first survey on July 7th (Table 1 and Figure 4). Biomass estimates declined subsequent to this, increased again on July 14th and then declined continuously throughout the spawning season. During the period of peak abundance, from July 7th to July 15th, the largest biomass estimates were derived from strata A, B and C, along the western shore. It was only during periods of low abundance (July 19th and 29th) that biomass estimates were larger along Bellevue Beach.

The peak biomass estimate in 1999 (3310 t) was 65% larger than the peak (2002 t) in 1998 (Figure 5). The peak abundance in 1999 was also detected two weeks earlier than in 1998. The abundance of capelin in 1999 was consistently higher than in 1998; biomass estimates from two surveys (July 7th and 9th) were larger than the peak

estimate in 1998, and estimates from two other surveys (July 13th and 14th) were comparable to the peak in 1998. The duration of high abundance in 1999 was approximately one week (July 7th - 15th); in 1998, it was more protracted over a two to three week period from mid-July onward.

2) Substrate Classification

For substrate classification within the survey area, mean particle sizes were divided into six groups ranging from sand to boulder (Figure 6). Sand was the most common substrate component, occurring at 24% of the sampled locations. Gravel and pebble (2 - 30 mm) occurred in 27% of the sampling sites; medium to large rock and boulders (60 - 201 mm) occurred at 42% of the sites. It was impossible to determine the substrate component at 8% of the sites due to the presence of a thick layer of capelin eggs.

Sand predominated off Bellevue Beach in particular towards the western end of the beach (Figure 6). Gravel and pebble occurred in pockets from Green Point to Bellevue Beach and also off the beach in particular towards the eastern end of the beach. Larger rock predominated in stratum C to the west of Bellevue Beach and in stratum D off the western end of Bellevue Island.

Capelin eggs were detected at 19% of the sampled sites (Fig. 7). However, they were only detected at gravel or pebble sites; none were detected at sites with sand or larger rock. The eggs were widely distributed geographically through the sampled area, from Green Point in the west to the eastern end of Bellevue Beach. They were also distributed widely where gravel or pebble occurred, being detected at 52% of the gravel sites and 39% of pebble sites. This was even more pronounced in the western part of the sampled area (strata A, B, and C) where eggs were detected at all of the sites where gravel occurred.

The capelin eggs were detected from sites that were videotaped between July 14th and July 21st. Capelin densities detected acoustically on July 7th were overlaid on the same map (Fig. 8). With very few exceptions, the distribution of capelin on July 7th was very similar to the subsequent distribution of capelin eggs.

Discussion

The peak biomass estimate from the acoustic surveys in1999 was 65% larger than in 1998. Some of this increase can be accounted for by increased fish size. Biological samples of capelin from Bellevue Beach indicated that the mean weight of fish increased by 17% from 1998 to 1999 (Nakashima 2000). Assuming that peak abundances were estimated in each of the years, this suggests an actual increase in fish abundance of approximately 50% from 1998 to 1999.

In 1999, peak densities and biomass were detected during the first acoustic survey of the field season (July 7th). This leads one to question whether this represents the actual peak for the season. On July 5th, an acoustic survey was attempted but could not be

completed due to an computer malfunction. However, the survey vessel *Topaz* did complete a run through the survey area. Observations recorded in the acoustic log indicated that there was a narrow 'band' of capelin along the western portion of Bellevue Beach and several smaller concentrations of capelin along the western shore to Green Head. This suggests that the high densities of capelin detected on July 7th moved into the survey area in the intervening period. However, it still does not indicate if the peaks detected on July 7th were the actual peaks for the spawning season. There may have been higher densities and a larger biomass within the area prior to July 5th.

Results from the 1999 Bellevue Beach egg and larval study (Nakashima 2000) indicate that peak beach spawning occurred from July 4th - 8th and that very few eggs were deposited subsequent to this. The acoustic results indicate that there were in excess of 2500 t of capelin in the survey area after beach spawning had occurred. Although no biological samples were taken, echograms and videotape indicate that these were pre-spawning fish. If these fish spawned in the area, then they must have done so sub-tidally (off-beach). The data support this conclusion as the incidence of capelin eggs at bottom sampling sites was widespread throughout the survey area and the distribution of capelin on July 7th relative to the location of these eggs was almost identical. It is also supported by the distribution of fish during the period of peak abundance. Most of the fish occurred in strata A and B along the western shore and not along the beach. Subsequently, eggs were detected at all of the sites with gravel in these strata.

The results indicate that off-beach spawning was widespread in the Bellevue area in 1999. In fact, based upon acoustic biomass estimates, it is conceivable that more capelin spawned off-beach (sub-tidally) in 1999 than spawned entirely in 1998. The implications of this in relation to larval emergence and the larval index from the egg and larval production study (Nakashima 2000) are uncertain. Larval tows, conducted adjacent to the beach as part of the egg and larval production study, would be unlikely to detect larvae from off-beach spawning. However, there were no larval tows directed beyond the off-beach spawning sites. This will be investigated further in 2000.

The percentages of capelin that spawned on the beach and off-beach in the Bellevue area in 1999 are unknown as acoustic biomass estimates were not available prior to beach spawning. Consequently, it is unknown what biomass produced the eggs that were deposited on the beach from July 4th to 8th. This aspect can be investigated further in 2000 by commencing the acoustic surveys earlier in the season.

Summary

- The peak biomass of capelin in the Bellevue survey area in 1999 was at least 50% greater than in 1998.
- Suitable capelin spawning substrate exists in depths to at least 20 m in the Bellevue survey area.
- Off-beach (sub-tidal) spawning was widespread in the Bellevue

area in 1999 and more capelin may have spawned sub-tidally in 1999 than spawned entirely in 1998.

- It is unknown if the relative proportion of beach spawning and off-beach spawning in 1999 differed from previous years.

References

Anon. 1997. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 97/29, 188 p.

Nakashima, B. 2000. Egg and larval production from Bellevue Beach, Trinity Bay in 1999. pp. In: Anon. Capelin in SA2 + Div. KL. CSAS Atl. Fish. Res. Doc. 2000/071.

Wheeler, J. P. and B. S. Nakashima. 1999. Acoustic and aerial observations of capelin (Mallotus villosus) schools during their spawning migration to a Newfoundland beach. Poster presented at the 129th Annual Meeting of the American Fisheries Society, August 1999.

Table 1. 1999 Bellevue capelin densities and biomass estimates, by stratum, and date.

	Densities (grams per square meter)					Biomass (t)					
Date	Strat. A	Strat. B	Strat. C	Strat. D	Strat. E	Strat. A	Strat. B	Strat. C	Strat. D	Strat. E	All Strata
07-Jul	832.29	1163.01	419.69	187.25	328.66	972.9	1582.8	391.1	363.3	260.9	3310.0
08-Jul											
09-Jul	850.64	633.91	455.74	127.39	146.88	994.3	862.7	424.7	247.1	116.6	2528.9
10-Jul											
11-Jul	169.99	273.20	313.51	26.28	153.41	198.7	371.8	292.1	51.0	121.8	984.5
12-Jul											
13-Jul	425.63	577.37	277.23	54.43	81.81	497.5	785.8	258.3	105.6	64.9	1647.2
14-Jul	354.71	881.05	7.02	54.03	19.42	414.6	1199.1	6.5	104.8	15.4	1725.0
15-Jul	123.44	309.81	82.05	31.11	18.88	144.3	421.6	76.5	60.4	15.0	702.7
16-Jul	18.28	133.79	112.95		6.89	21.4	182.1	105.3	0.0	5.5	314.2
17-Jul											
18-Jul											
19-Jul	21.51	19.48	40.28	114.53	94.80	25.1	26.5	37.5	222.2	75.3	311.4
20-Jul											
21-Jul											
22-Jul	64.43	78.65	6.24		0.00	75.3	107.0	5.8	0.0	0.0	188.2
23-Jul											
24-Jul											
25-Jul											
26-Jul											
27-Jul											
28-Jul											
29-Jul	24.09	21.90	0.00	21.98	15.93	28.2	29.8	0.0	42.6	12.6	100.6

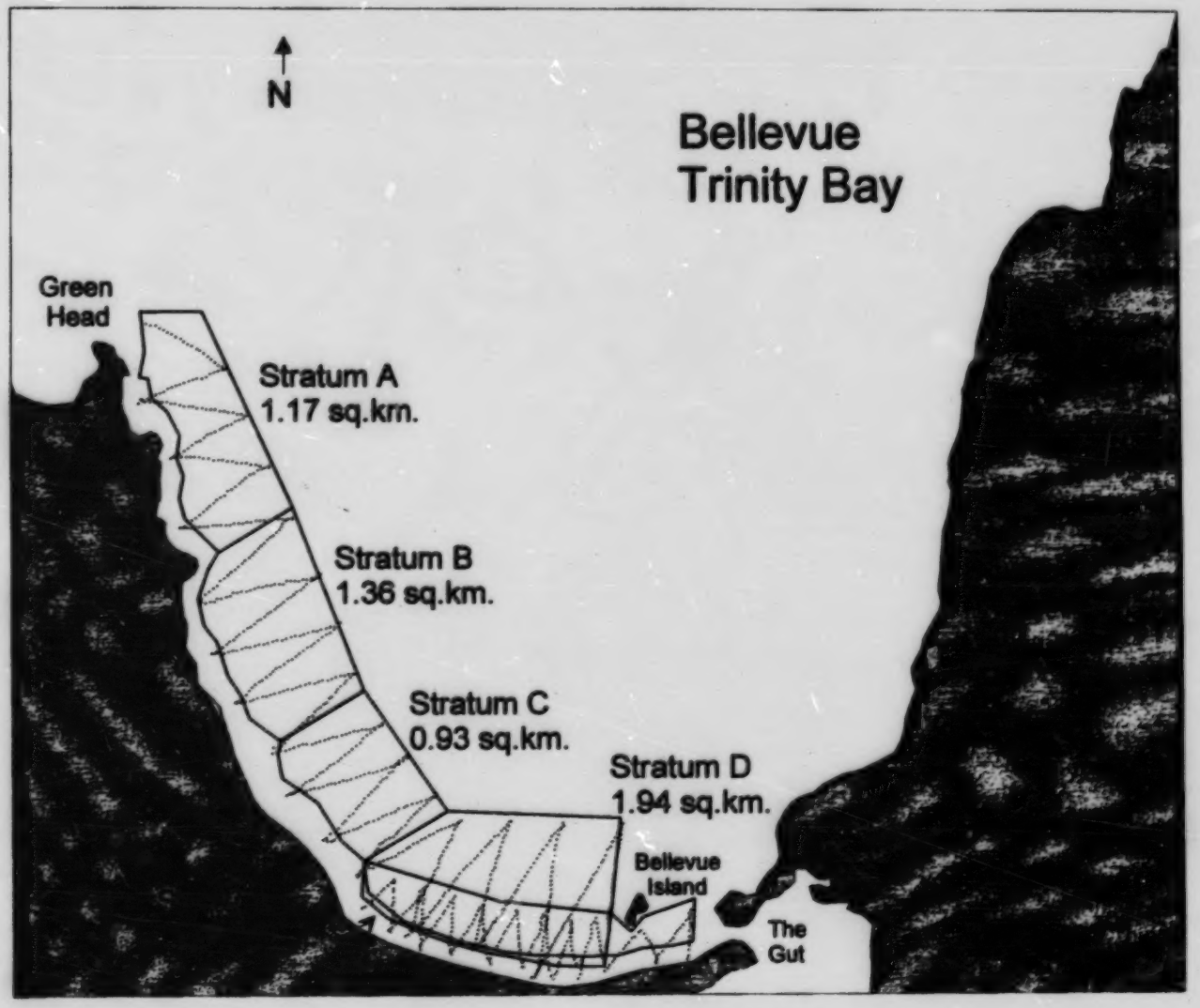

Figure 1. Acoustic survey strata and transects, Bellevue, Trinity Bay.

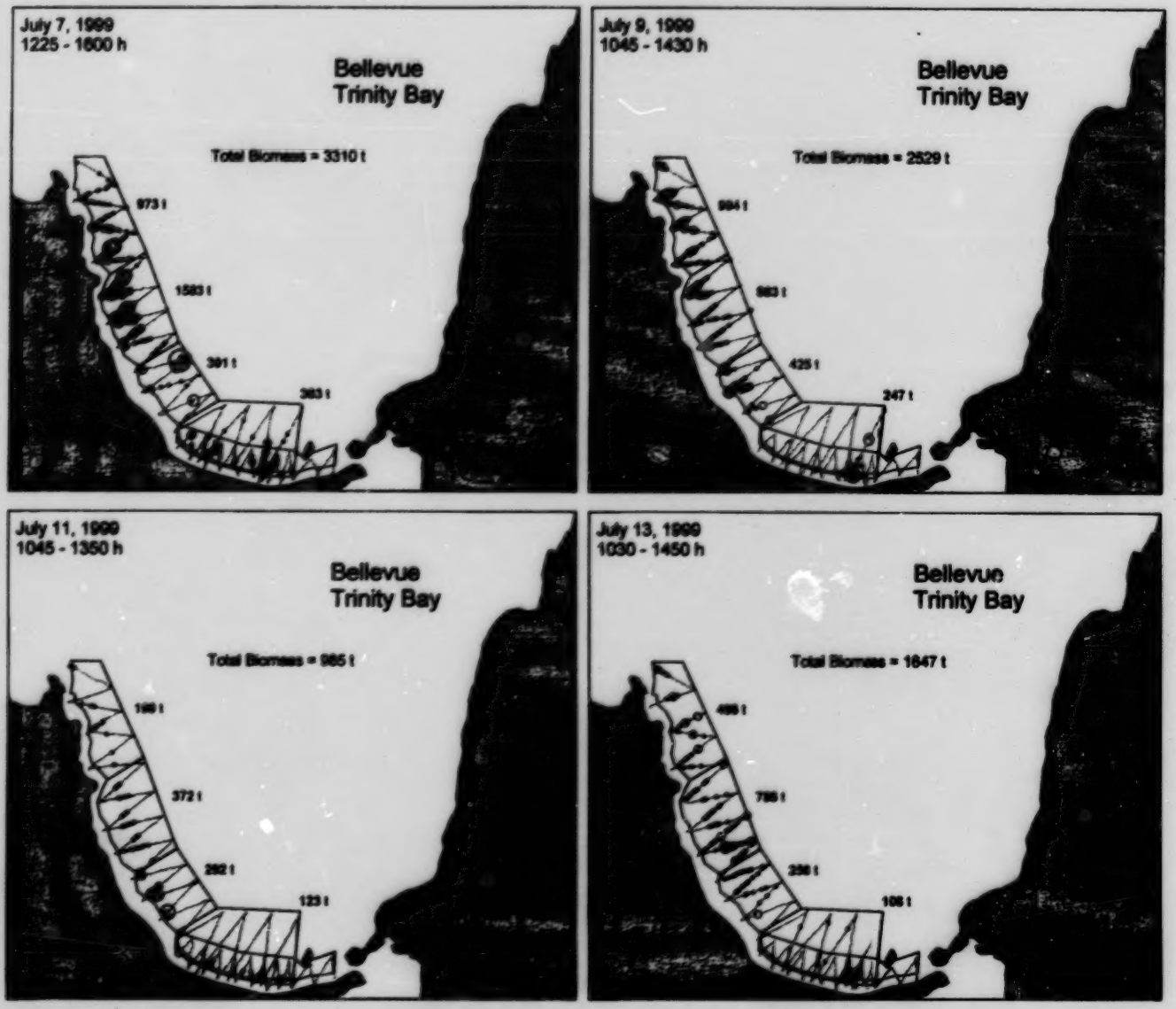

Figure 2. Bellevue capelin densities and biomass estimates, by stratum, July 7 - 13, 1999.

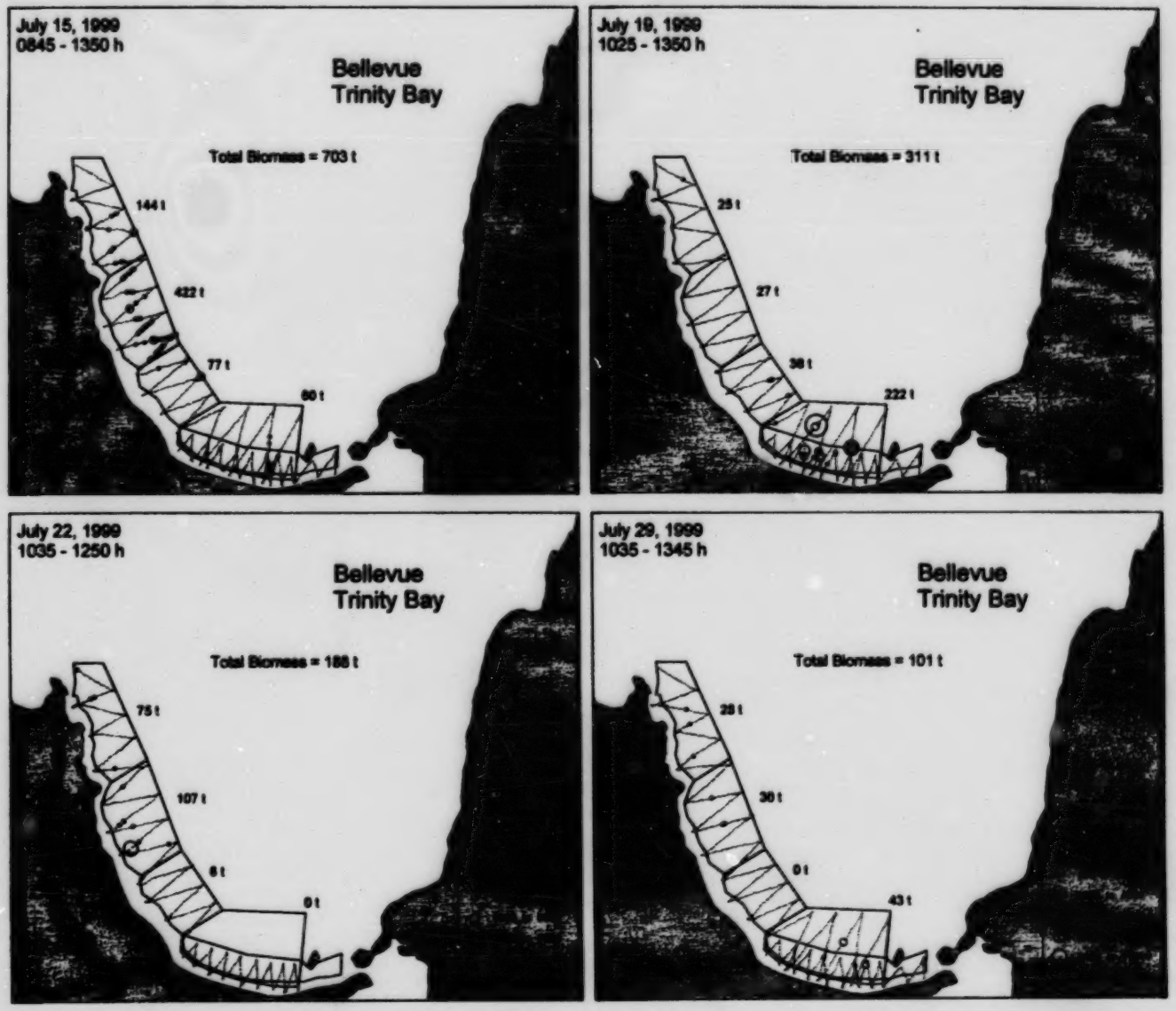

Figure 3. Bellevue capelin densities and biomass estimates, by stratum, July 15 - 29, 1999.

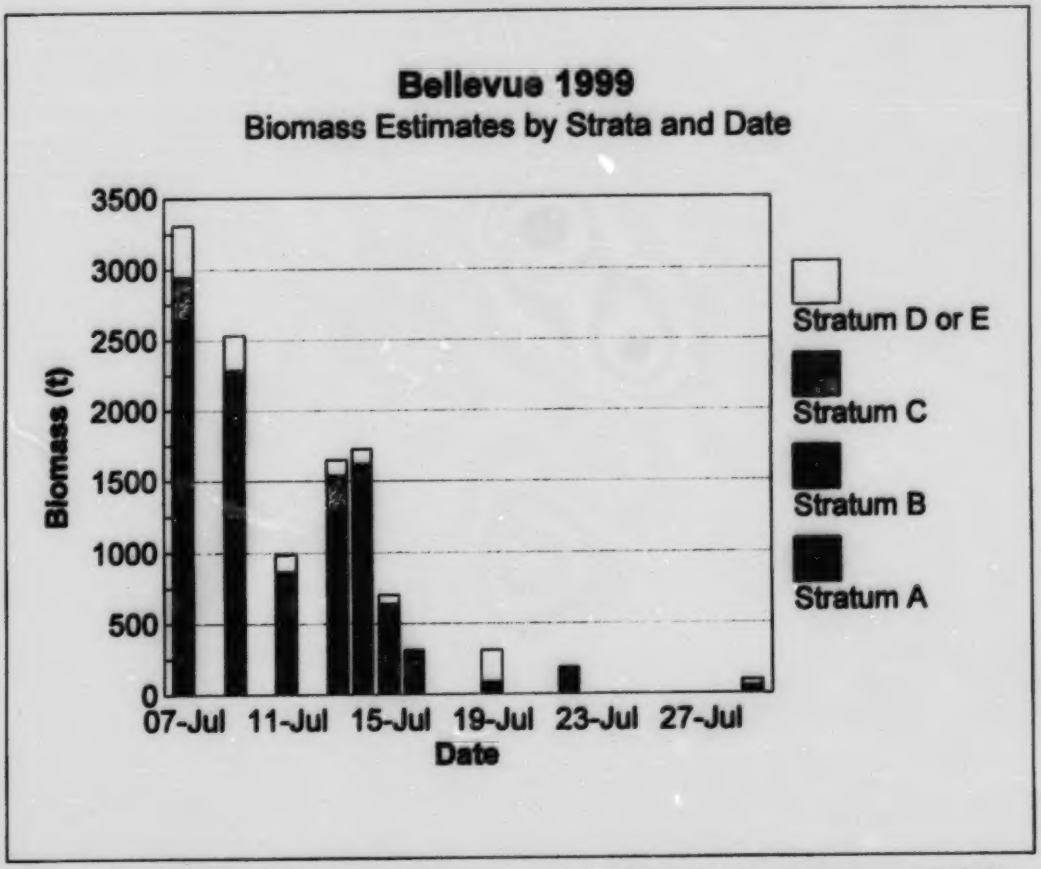

Figure 4. 1999 Bellevue capelin biomass estimates by stratum and date.

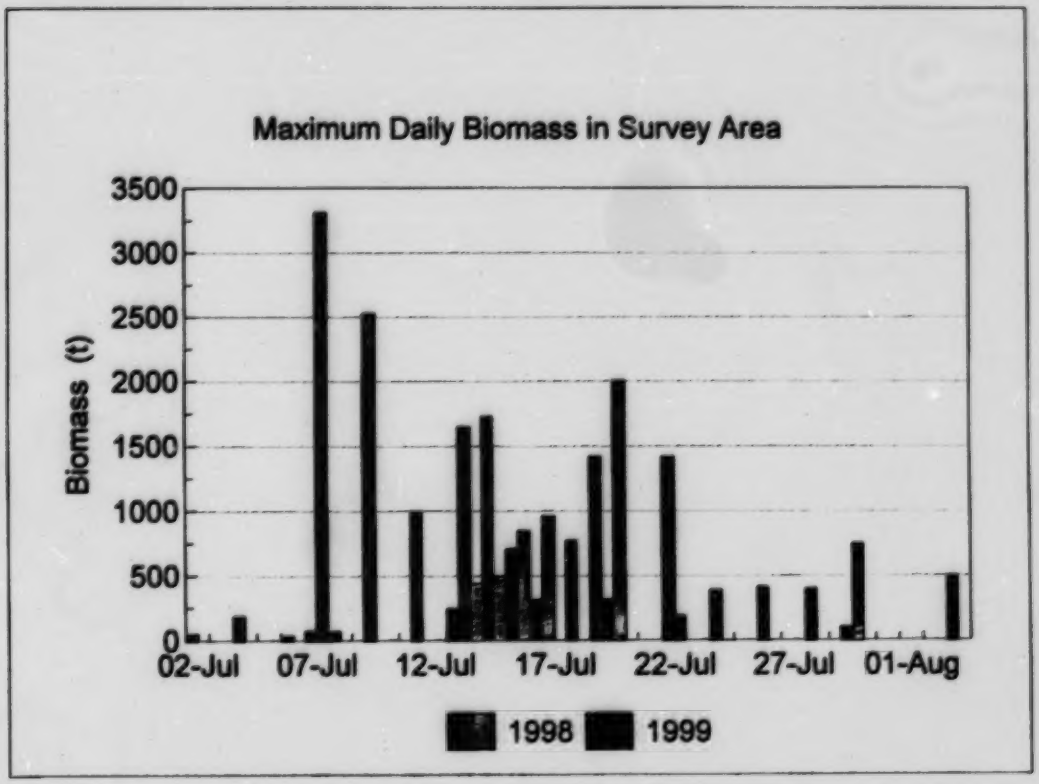

Figure 5. Comparison of maximum daily capelin biomass estimates within the Bellevue survey area in 1998 and 1999.

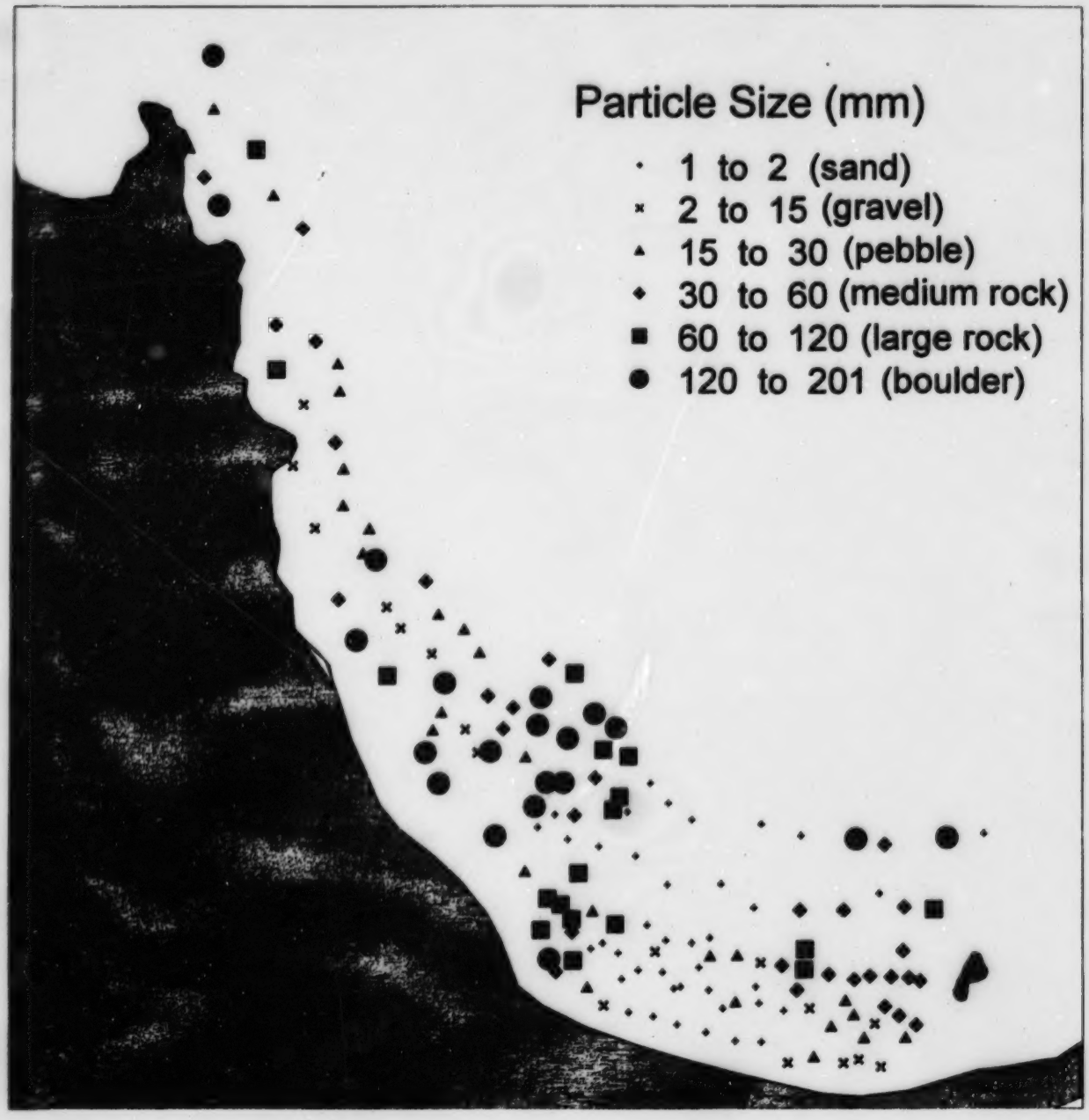

Figure 6. Mean particle size of bottom substrate at selected sites in Bellevue, Trinity Bay, as calculated from video images.

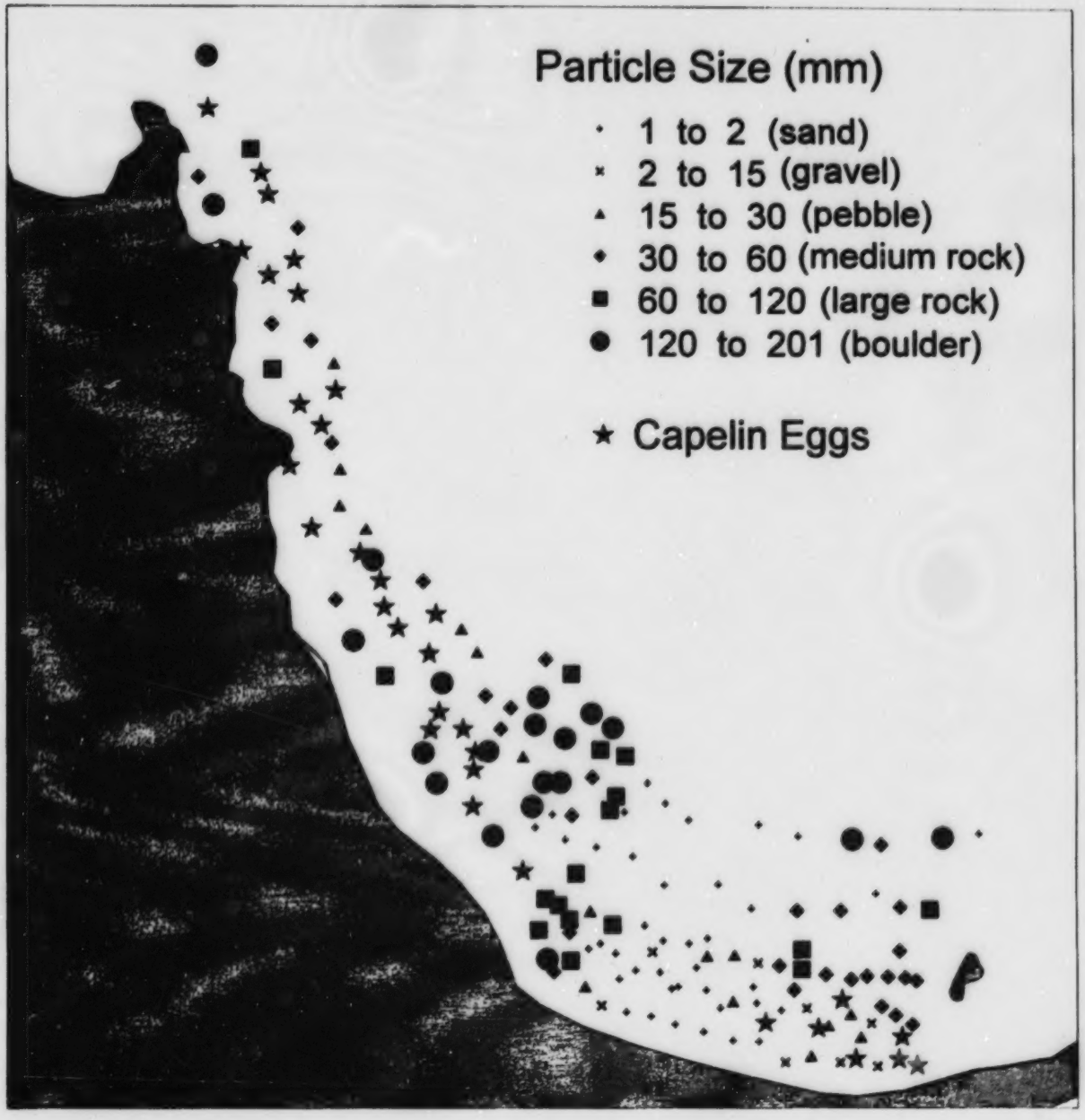

Figure 7. Mean particle size of bottom substrate at selected sites and locations where capelin eggs were detected, as determined from video images.

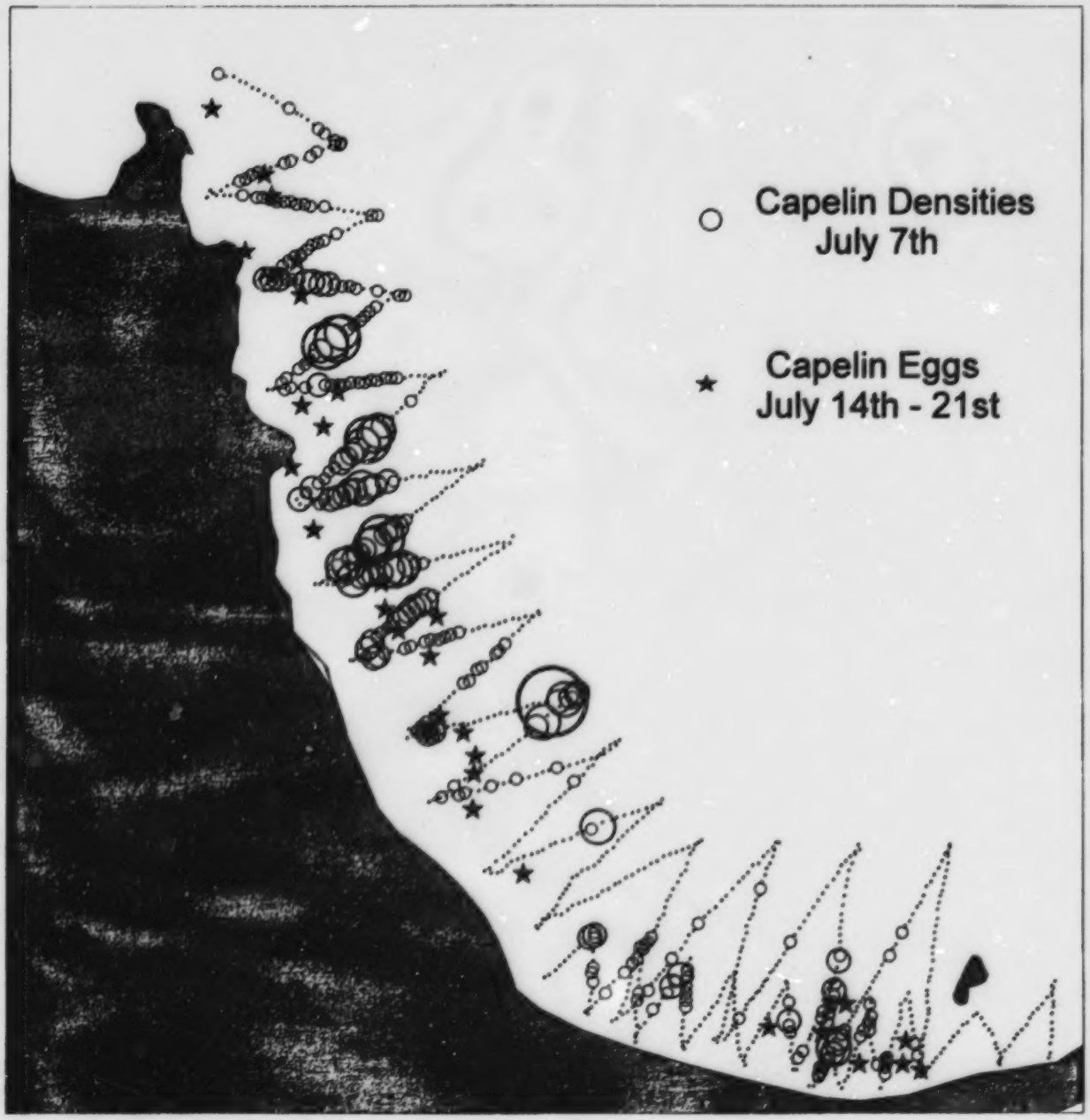

Figure 8. Location of capelin detected acoustically and subsequent locations of capelin eggs detected from video images.

Acoustic surveys for capelin in Placentia Bay, June 1998-1999

by

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Abstract

The abundance, distribution and biological composition of capelin (*Mallotus villosus*) in Placentia Bay was assessed during an acoustic survey in June 1999. Capelin biomass in outer Placentia Bay and a portion of 3Ps was estimated as 20,000 tons. This was a substantial decrease from June 1998, when 203,000 tons of capelin was detected in the same area. The acoustic survey in 1999 was 2-3 weeks earlier than in 1998 and it is possible that capelin had not yet migrated into the survey area. Approximately half of the capelin sampled were maturing. Immature capelin were concentrated in an area to the south of the Burin Peninsula, while mature capelin were caught throughout the bay. Capelin from Placentia Bay were smaller-at-maturity and smaller-at-age than capelin from Trinity Bay (3L) or Labrador (2J). The length of 50% maturity was 120mm for females and 140mm for males.

Introduction

Acoustic surveys for cod and capelin are conducted regularly in Placentia Bay (NAFO Div. 3Ps) by the Fisheries Conservation group at Memorial University of Newfoundland. O'Driscoll & Rose (1999) summarised the results from four surveys in 1998-99, and showed that distribution and abundance of capelin in Placentia Bay varied seasonally. Capelin biomass was highest in June 1998, when over 130,000 tons were detected in the outer part of the bay. In this paper, we present a more spatially extensive estimate of capelin abundance from June 1998, including a portion of 3Ps out to the edge of the St. Pierre and Green Banks. We compare this new estimate with capelin biomass in the same region from our June 1999 survey. We also present

biological data on capelin growth and maturity in Placentia Bay.

Methods

Surveys were conducted from the research vessel *Teleost* during June 19-25 1998 (Teleost 65) and June 1-4 1999 (Teleost 79). Acoustic data was collected using a calibrated Simrad EK500 split-beam 38-kHz echo-sounder (Table 1), and analysed using custom FASIT (Fisheries Assessment and Species Identification Toolkit) software. We distinguished signals from capelin based on signal characteristics and information from fishing sets.

For biomass estimation, we integrated acoustic data from 11m below the surface to the bottom in 100-m horizontal bins and scaled by acoustic target strength to give estimates of areal density of capelin (fish m^{-2}) in each 100-m bin. Mean target strengths for each survey (Table 2) were calculated from fishing set length-frequency data using the relationship TS = 20logL - 73.1 where L = fish length in centimetres (Rose 1998).

The area surveyed included the outer part of Placentia Bay and a corridor straddling the edges of St. Pierre and Green Banks out to the shelf edge (Fig. 1). Ten blocks were used as the basis for the survey and transects were run across the blocks (Fig. 1). These blocks are identical to those used in calculation of cod biomass from the same surveys (e.g. Rose & Lawson 1999).

Only data collected along transects were used to estimate biomass, although all data, including inter-transect segments are shown in Fig. 1. Capelin biomass was estimated independently for each block from the equation:

$$B_i = w\, A_i d_i$$

where B_i is the biomass of capelin in block i (kg)
w is the average weight of capelin from fishing sets (kg)
A_i is the area of block i (m^2)
d_i is the mean areal density of capelin in block i (fish m^{-2})

Acoustic data in 100-m bins were significantly autocorrelated. To estimate sampling uncertainty we used a

bootstrapping method (Robotham & Castillo 1990) for each block based on repeated 10% sampling of the 100-m binned data (100 times). There was usually no significant autocorrelation in the 10% sampled data. The 100 sample means were used to calculate the bootstrapped mean density (d_i) and 95% confidence intervals for each block (Tables 3-4).

Fishing sets with Campelen bottom and IYGPT mid-water trawls were carried out in support of the acoustic surveys (Fig 2). Length composition of capelin was determined from a random sample of 200 fish per set in 1998 and 1999. Detailed biological analyses were also carried out on a length-stratified sub-sample (10 capelin in each 1-cm length class) of fish from each set in June 1999 (Table 5). We compare biological characteristics of capelin from Placentia Bay with fish sampled during the same cruise in Trinity Bay (NAFO 3L) and southern Labrador (NAFO 2J).

Results

The acoustic estimate of capelin biomass in our survey area in June 1999 was 20,000 tons (95% confidence intervals 12,000-29,000t) (Table 4). This was an order of magnitude lower than the equivalent biomass estimate from June 1998 of 203,000 tons (135,000-303,000t) (Table 3).

Spatial distribution of capelin was also different between 1998 and 1999 (Fig. 1). In June 1998 highest densities of capelin were observed in the northern part of the study area (blocks b and c). In June 1999 highest densities were in block g to the south of Placentia Bay.

Mean lengths of capelin from Placentia Bay were similar in 1998 (125mm) and 1999 (124mm) (Fig. 3). However, a lower proportion of large capelin (>130mm) were observed in 1999. Approximately 50% of capelin sampled were sexually mature in 1999. A mix of mature and immature capelin was captured in all fishing sets (Fig. 2). Immature capelin were most abundant in sets to the south of the Burin Peninsula in block g and in the north-eastern part of the survey area in block a (Fig. 2).

Capelin from Placentia Bay matured at smaller size than capelin from Labrador or Trinity Bay (Fig. 4). Length at 50% maturity was 120mm for females and 140mm for males, compared to 130mm for females and 150mm for males from

Trinity Bay and Labrador. There was no evidence that capelin in Placentia Bay were maturing at younger ages than capelin in the other areas (Fig. 5). At age two 24% of males and 55% of females were mature in Placentia Bay, compared to 29% of males and 83% of females in Labrador and 31% of males and 49% of females in Trinity Bay. Rather, mature capelin from Placentia Bay seemed to be smaller at age than capelin from Labrador and Trinity Bay (Fig. 6). This difference in growth was particularly apparent for females (Fig. 6).

Discussion

O'Driscoll & Rose (1999) showed that capelin abundance and distribution varied seasonally in Placentia Bay. Biomass estimates in a "common area" of outer Placentia Bay (bounded by co-ordinates: 47°23'N, 54°29'W; 47°20'N, 54°01'W; 46°45'N, 55°31'W; 46°43'N, 54°19'W) were highest in June 1998 and lowest in January 1999 (Fig. 7). Estimated capelin biomass in this common area in June 1999 was 4,500t, which was ten times greater than biomass in January 1999, but much less than biomass in January and June 1998 (Fig. 7). Our survey was ~18 days earlier in 1999 than in 1998. The southward distribution of capelin in 1999 suggests that all fish may not yet have migrated into our study area. However, independent acoustic surveys for cod in fall 1999 (Luiz Mello pers. comm.) and discussions with local residents (Byron Adams pers. comm.) indicate that the abundance of capelin in Placentia Bay was much lower in 1999 than in 1998.

The reduction of capelin biomass between June 1998 and June 1999 also reflects relative year-class strength. Most (86%) capelin sampled in June 1999 were age two (1997 year-class). If the same age structure was present in Placentia Bay in 1998 as in 1999, capelin biomass in June 1998 would have been dominated by the strong 1996 year-class. The 1997 year-class we observed in June 1999 is thought to be much weaker (Anderson *et al.* 1999).

No biological sampling of capelin was carried out in June 1998. Because of the small size of the capelin sampled, O'Driscoll and Rose (1999) assumed that almost all capelin in Placentia Bay in June 1998 were immature. Our results from 1999 indicate that this is incorrect. Using the maturity-at-length data from 1999 (Fig. 4) and the length frequencies observed in 1998 (Fig. 3) we calculated

that 53% of capelin observed in June 1998 were pre-spawning adults. Hence, there would have been substantial spawning mortality of the larger capelin (>120mm) between 1998 and 1999.

The low length-at-maturity and apparent slow growth of capelin in Placentia Bay compared to capelin from Trinity Bay and Labrador was an unexpected result. Winters (1982) observed a north-south cline in capelin growth, where growth was more rapid further south. He attributed this cline to warmer water temperatures in the south. Winters (1982) did not sample capelin from Placentia Bay, but capelin from Grand Beach in Fortune Bay exhibited a similar growth pattern to fish from Trinity Bay and grew faster than capelin from Labrador. Work on the growth and feeding behaviour of capelin in this area is ongoing.

Acknowledgements

We thank the sea-going scientific staff and crew of the "CGSS Teleost" and Phil Eustace who aged the capelin samples. Funding for this work came from the NSERC Industrial Chair in Fisheries Conservation and from a New Zealand Foundation for Research, Science and Technology Post-Doctoral Fellowship held by the first author.

References

Anderson, J.T., Dalley, E.L. and Davis, D.E. 1999. Year-class strength of northwest Atlantic capelin (2J3KLNO) estimated at the larval stage and age one based on pelagic juvenile fish surveys 1994-1998. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206.

O'Driscoll, R.L. and Rose, G.A. 1999. Seasonal changes in abundance, distribution and vertical migration of capelin in Placentia Bay. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206.

Robotham, H. and Castillo, J. 1990. The bootstrap method: an alternative for estimating confidence intervals of resources surveyed by hydroacoustic techniques. Rapp. P.-v. Reun. Cons. int. Explor. Mer 189: 421-424.

Rose, G.A. 1998. Acoustic target strength of capelin in Newfoundland waters. ICES J. Mar. Sci. 55: 918-923.

Rose, G.A. and Lawson, G.L. 1999. Acoustic surveys in Placentia Bay and 3Ps, June 1996-1998. CSAS Res. Doc. 99/41. 15pp.

Winters, G.H. 1982. Life history and geographical patterns of growth in capelin, *Mallotus villosus*, of the Labrador and Newfoundland areas. J. Northw. Atl. Fish. Sci. 3: 105-114.

Table 1. Specifications for EK500 on Teleost surveys in June 1998 and 1999.

	1998	1999
Frequency	38kHz	38kHz
Ping Interval	1s	1s (250m range) 2s (500m)
Pulse length	1.0ms	1.0ms
Bandwidth	3.8kHz	3.8kHz
Transmit Power	2000W	2000W
Absorption Coefficient	10dB km^{-1}	10dB km^{-1}
2-Way Beam Angle	-20.6 dB	-20.6 dB
Sv Transducer Gain	25.60 dB	26.00 dB
TS Transducer Gain	25.60 dB	25.82 dB
TVG	20logR	20logR
Angle Sensitivity Along.	21.9	21.9
Angle Sensitivity Athw.	21.9	21.9
3 dB Beamwidth Along.	7.1 dg	7.0 dg
3 dB Beamwidth Athw.	7.1 dg	7.0 dg
Along. Ship Offset	0.00 dg	-0.13 dg
Athw. Ship Offset	0.00 dg	-0.15 dg
Range of Raw Sv data collection	250m or 500m	250m or 500m
Vertical Sampling Resolution	0.1m	0.1m
Bottom Removal	none on raw data	none on raw data
Vessel Speed	8 knots	8 knots

Table 2. Capelin target strength calculated from length-frequency data for surveys in Placentia Bay in June 1998 and 1999.

Survey	Mean σ (m^2)	Mean TS (dB)	Mean length (mm)	Mean weight (g)
June 1998	9.846E-05	-51.06	125	10.34
June 1999	9.485E-05	-51.22	124	9.50

Table 3. Capelin abundance and biomass estimates for survey June 19-25 1998 (see Fig. 1 for block boundaries).

Survey Block	No. of 100-m bins	Mean capelin density m^{-2} (d_i) (95% CI)	Transect area ($*10^6$ m^2)	Stratum abundance (millions) (95% CI)	Stratum biomass (tons) (95% CI)
a	340	2.63	170	448	4633
		(0.75-5.01)		(127-852)	(1316-8813)
b	370	4.60	396	1820	18830
		(3.30-6.34)		(1310-2510)	(13521-25940)
c	553	4.94	462	2280	23621
		(2.75-7.91)		(1270-3660)	(13137-37841)
d	503	3.15	390	1230	12689
		(1.38-5.41)		(537-2110)	(5549-21828)
e	617	3.65	1050	3820	39479
		(2.59-4.79)		(2710-5020)	(28018-51931)
f	777	1.98	1630	3230	33389
		(1.46-2.34)		(2390-3830)	(24719-39569)
g	1003	1.12	4230	4730	48950
		(0.80-1.76)		(3380-7420)	(34944-76703)
h	710	0.48	3700	1780	18461
		(0.31-0.78)		(1150-2890)	(11918-29846)
i	642	0.004	3940	18	183
		(0.002-0.008)		(6-32)	(65-335)
j	1094	0.08	3630	287	2972
		(0.04-0.27)		(140-978)	(1450-10117)
Total			19600	19600	203208
				(13000-29300)	(134636-302923)

Table 4. Capelin abundance and biomass estimates for survey June 1-4 1999 (see Fig. 1 for block boundaries).

Survey Block	No. of 100-m bins	Mean capelin density m^{-2} (d_i) (95% CI)	Transect area ($*10^6$ m^2)	Stratum abundance (millions) (95% CI)	Stratum biomass (tons) (95% CI)
a	328	0.007	170	1	12
		(0.001-0.016)		(0.2-3)	(2-26)
b	405	0.007	396	3	28
		(0.002-0.017)		(1-7)	(9-63)
c	474	0.022	462	10	95
		(0.009-0.048)		(4-22)	(41-210)
d	476	0.013	390	5	48
		(0.006-0.038)		(2-15)	(2-139)
e	676	0.012	1050	13	119
		(0.007-0.019)		(7-20)	(68-187)
f	754	0.132	1630	215	2045
		(0.068-0.233)		(111-379)	(1056-3604)
g	1048	0.282	4230	1190	11314
		(0.157-0.405)		(665-1710)	(6313-16272)
h	2402	0.165	3700	609	5781
		(0.119-0.207)		(441-763)	(4186-7251)
i	884	0.009	3940	36	339
		(0.005-0.014)		(20-54)	(191-509)
j	2235	0.011	3630	39	373
		(0.003-0.031)		(11-112)	(103-1060)
Total			19600	2120	20154
				(1260-3090)	(11970-29321)

Table 5. Biological sample sizes from June 1999 cruise.

Set Number	Gear Type	Catch	Number measured	Number LWSM	Number aged
3	Campelen	2455	200	45	20
5	Campelen	2405	200	39	4
6	Campelen	8591	200	49	0
7	Campelen	4503	200	46	0
8	Campelen	48	48	18	8
9	Campelen	468	200	59	0
10	Campelen	201	201	50	0
11	Campelen	1491	200	56	19
12	IYGPT	8522	200	50	12
13	IYGPT	568	200	63	5
14	Campelen	12085	200	56	16
15	Campelen	2323	200	60	10
17	Campelen (mid-water)	619	200	56	4
Total		44279	2449	647	98

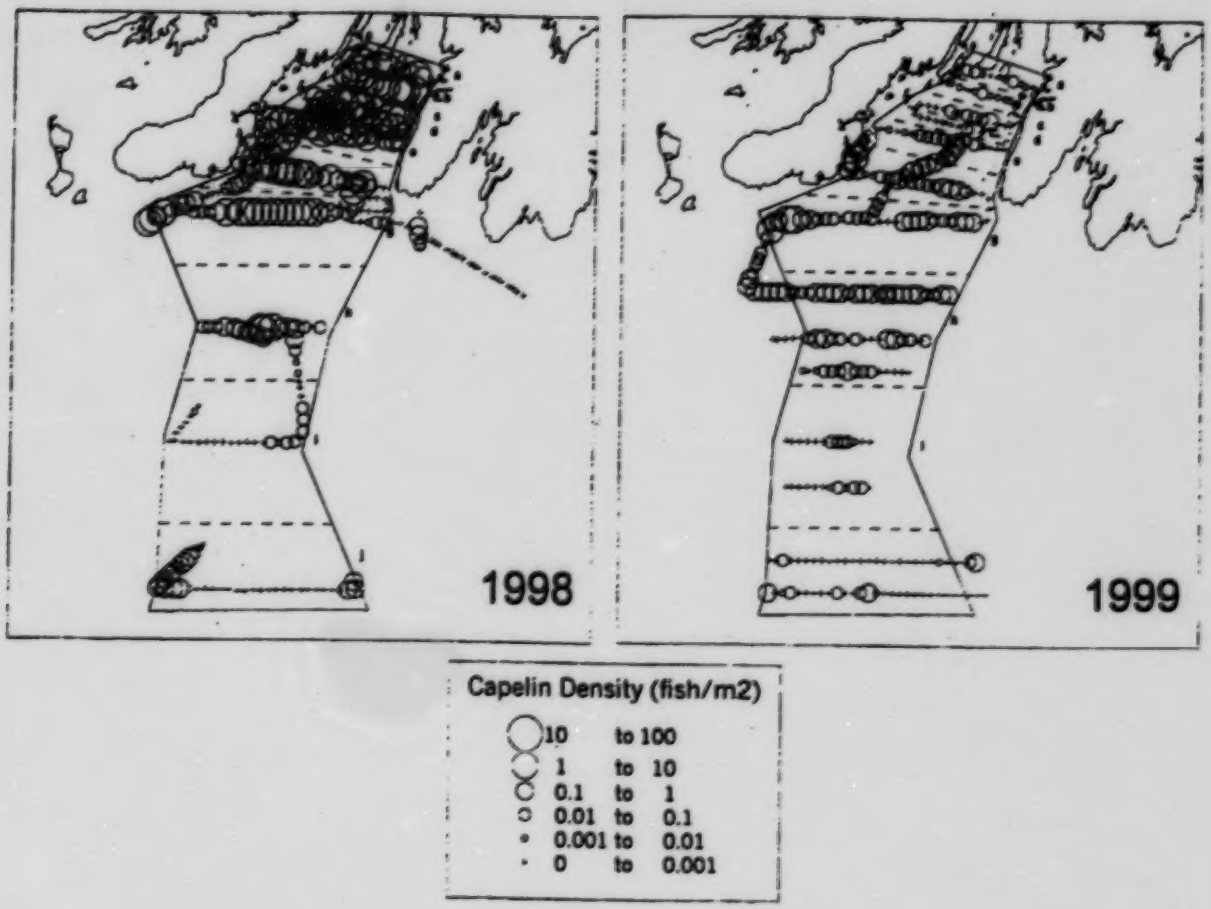

Fig. 1. Expanding symbol plot showing capelin distribution in Placentia Bay and a portion of 3Ps during surveys in June 1998 and 1999. Acoustic data were averaged into 5-km bins for the purpose of display. '+' symbol indicates no capelin were detected in that bin. Blocks used for estimating biomass are indicated and lettered.

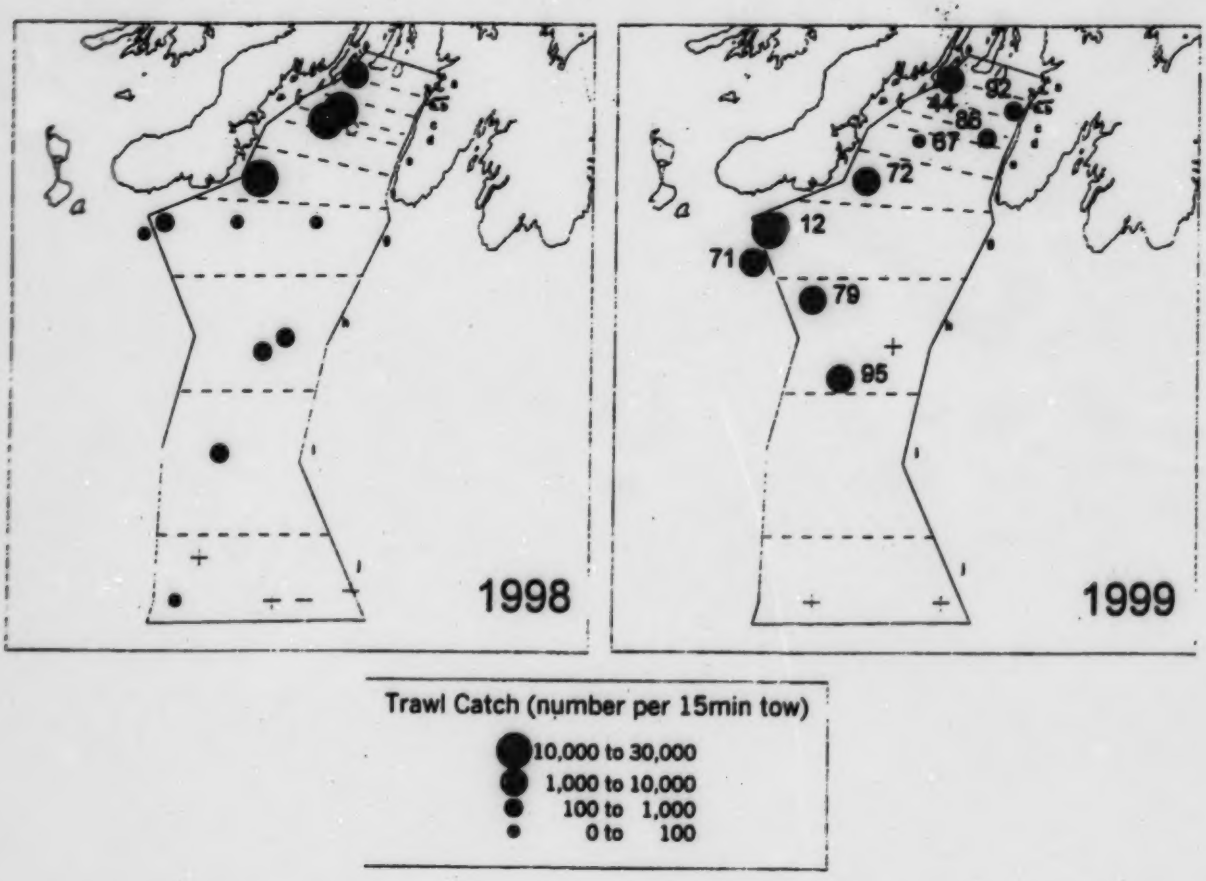

Fig. 2. Locations of fishing sets during surveys in June 1998 and 1999. Circle size is proportional to catch. Open circles show IYGPT mid-water trawls. Closed circles show Campelen bottom trawls. '+' symbol indicates no capelin were caught. Numbers next to symbols in 1999 indicate proportion of capelin in each set that were sexually mature.

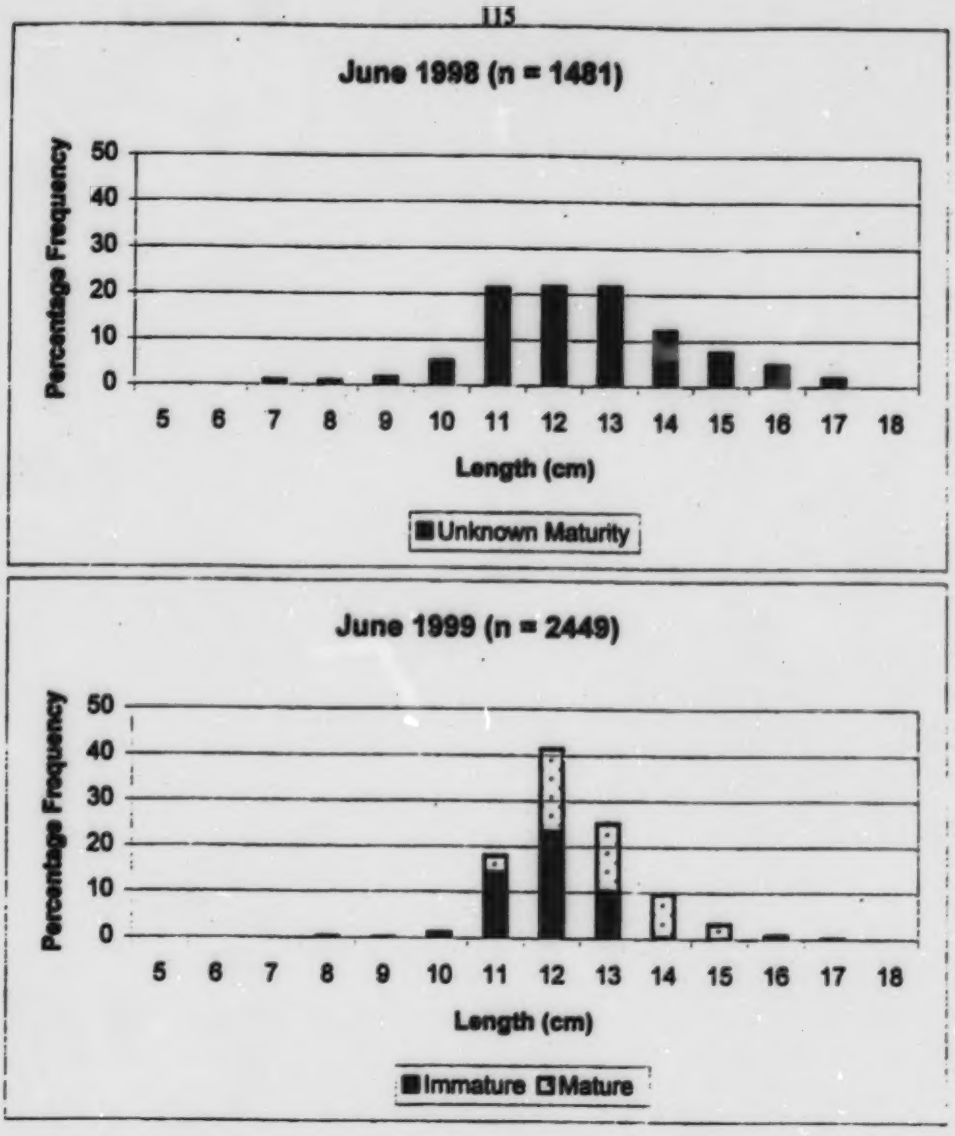

Fig. 3. Length frequency distributions of capelin sampled during acoustic surveys. The total number of fish measured (n) is given.

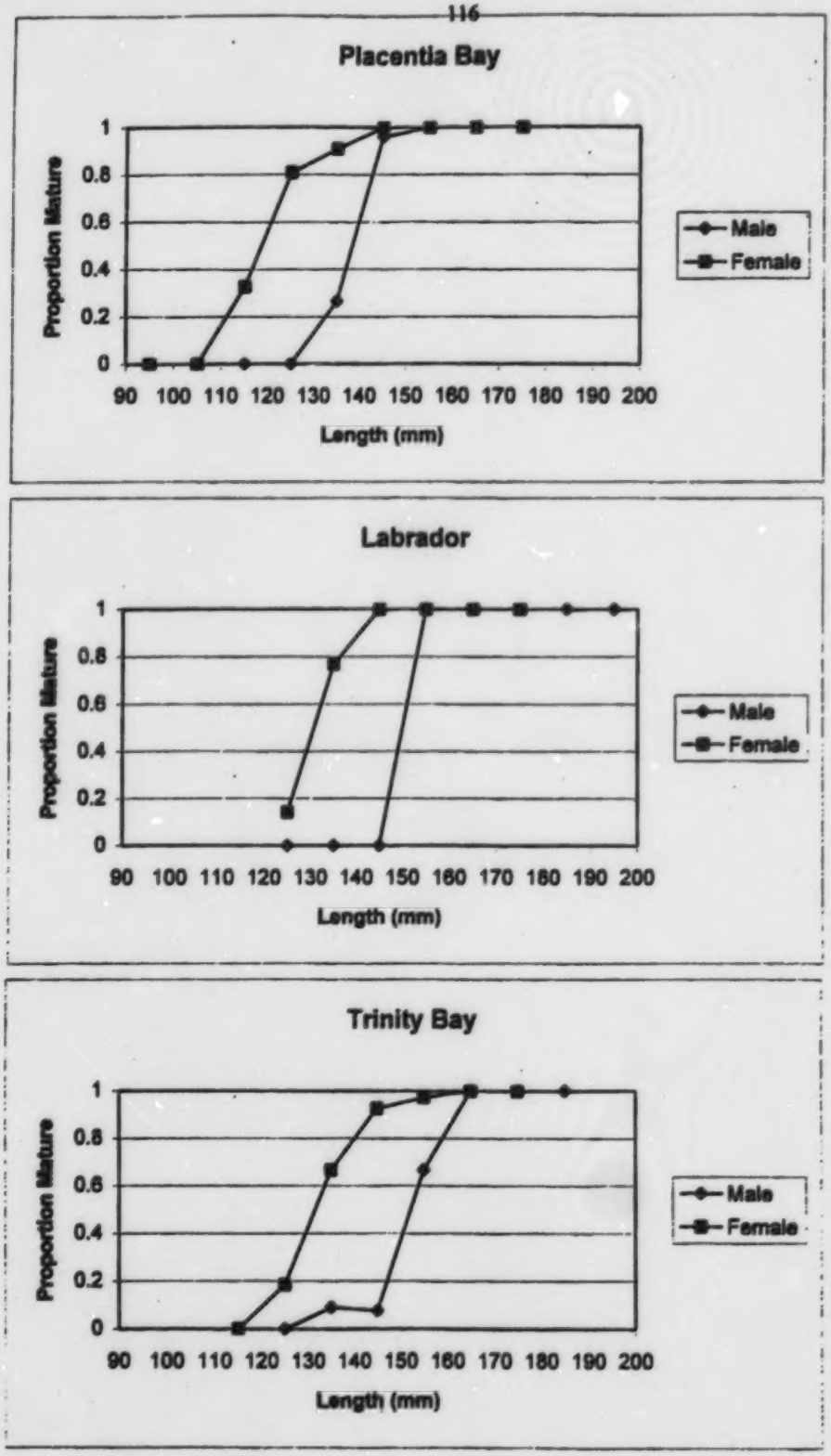

Fig. 4. Comparison of proportion mature at length for capelin sampled in Placentia Bay, Labrador and Trinity Bay.

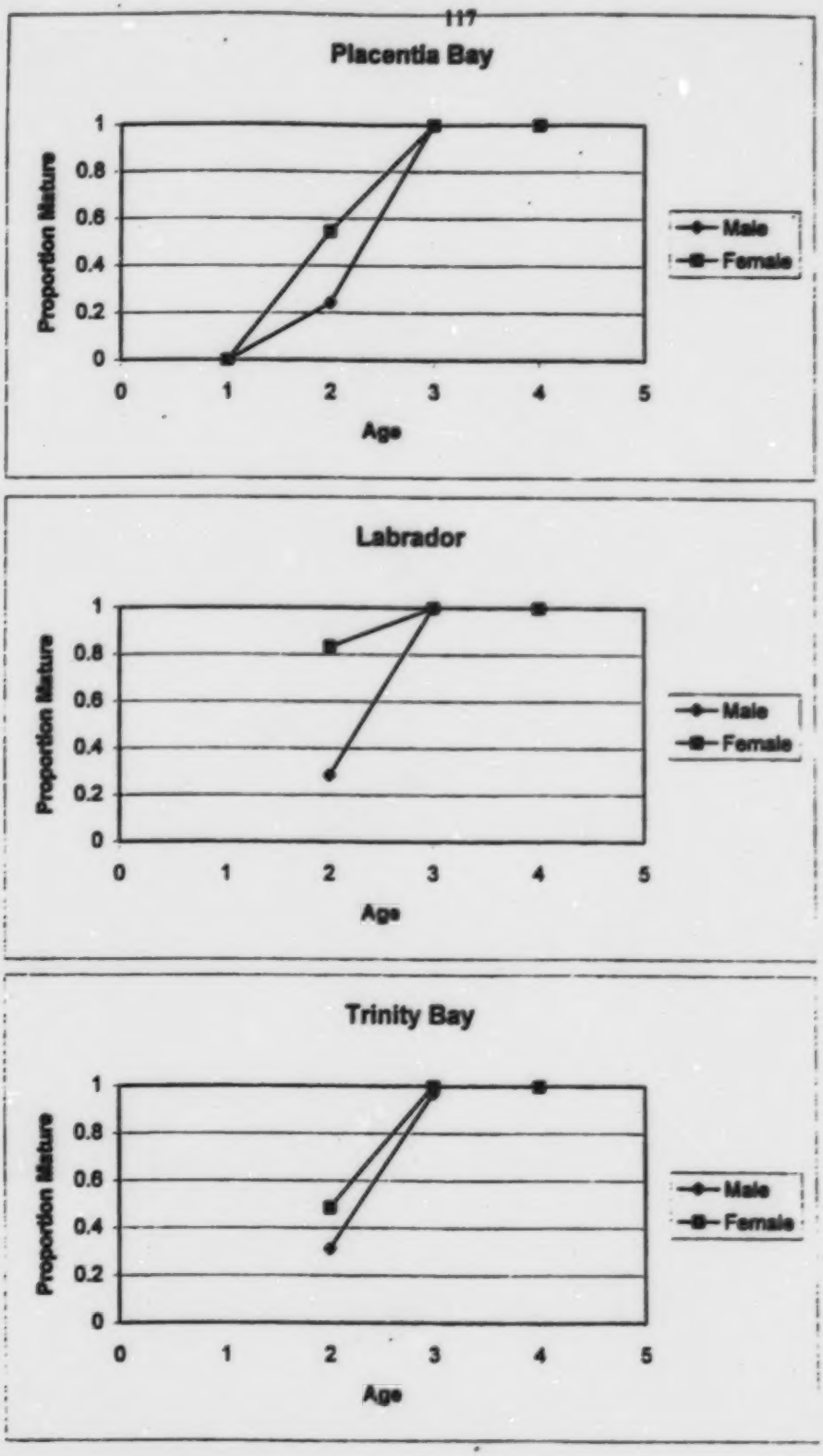

Fig. 5. Comparison of proportion mature at age for capelin sampled in Placentia Bay, Labrador and Trinity Bay.

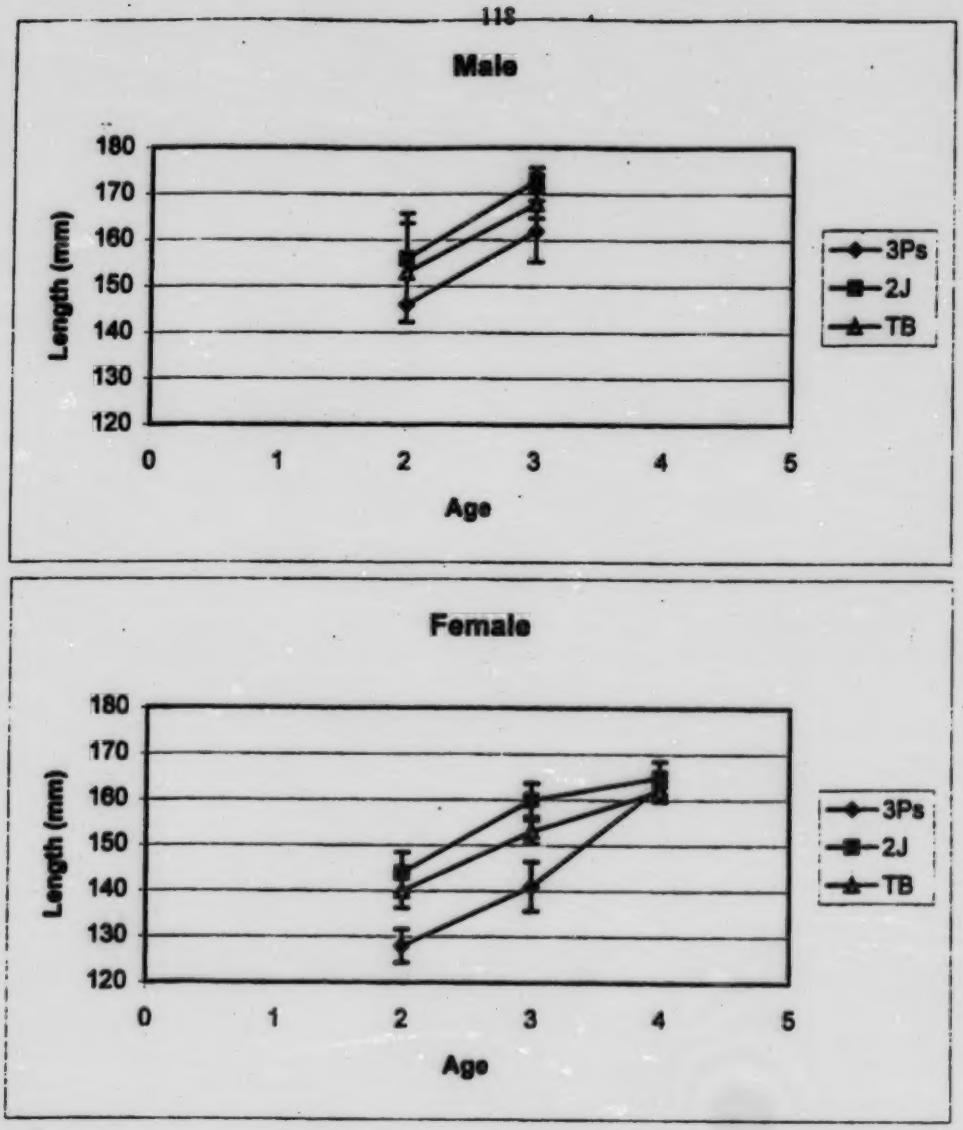

Fig. 6. Comparison of mean length at age of mature capelin sampled in Placentia Bay (3Ps), Labrador (2J) and Trinity Bay (TB). Error bars show +/- 2 standard errors.

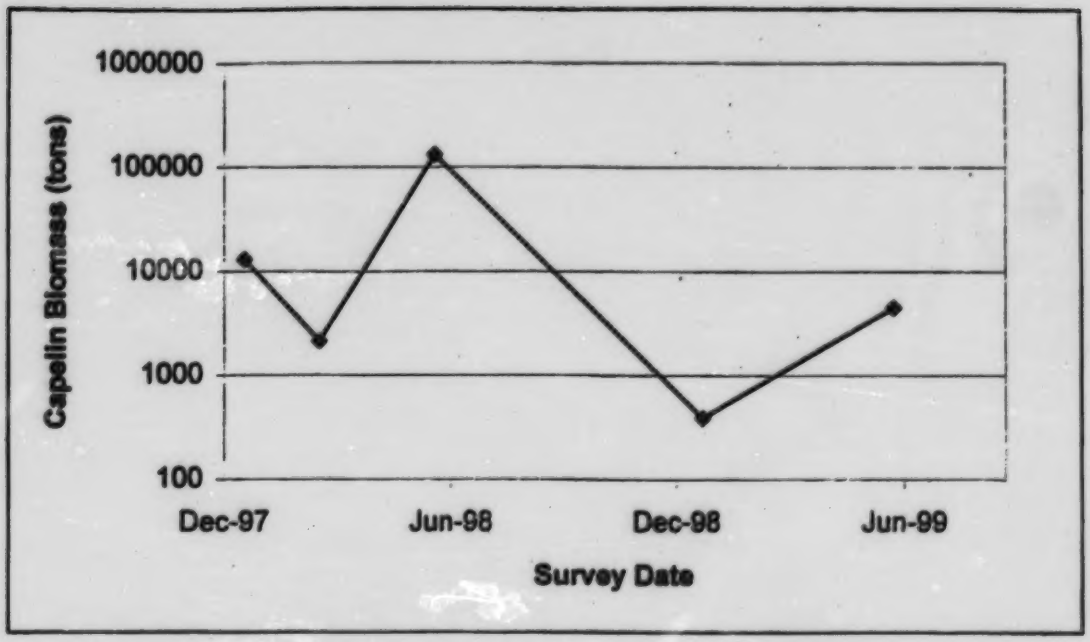

Fig. 7. Change in acoustic estimates capelin biomass for a "common area" of outer Placentia Bay surveyed in January, March and June 1998, and January and June 1999. Note capelin biomass is presented on a logarithmic scale.

Abundance and distribution of capelin from an acoustic survey in conjunction with the 1999 Pelagic Juvenile Survey

by

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Abstract

Acoustic data on capelin distribution and abundance in 2J3K were collected during the fall pelagic juvenile trawl survey from 1997-1999. In 1997-1998 only processed acoustic data were recorded. The 1999 survey was the first attempt to collect high-resolution acoustic data that allows post-processing and signal discrimination. Capelin distribution shifted northward from 1997 to 1999. In 1999 capelin were most abundant off southern Labrador. Capelin abundance offshore in 2J3K was estimated as 69,000 tons (33,000-116,000 tons) in 1999 using a capelin target strength of -34 dB kg^{-1}. This estimate is similar to biomass estimates from comparable Canadian fall acoustic surveys in 1990 and 1991 and lower than all estimates from the 1980s. A recent length-based model of capelin target strength was also applied to data from 1999. This model indicated that the target strength of -34 dB kg^{-1} used in previous Canadian acoustic surveys overestimates abundance of most (< 18cm) capelin. Using the new target strength model, absolute abundance of capelin in the surveyed region was 5.3 billion fish (3.4-7.3 billion) equivalent to 43,000 tons (27,000-61,000 tons). Other sources of uncertainty in the absolute acoustic estimate of biomass are also considered. The pelagic juvenile survey provides an excellent framework within which to conduct continuing acoustic research on capelin. The only major concession

required in a future combined trawl/acoustic surveys is allowance for more targeted fishing sets to identify near-bottom concentrations of capelin.

Introduction

Acoustic surveys for capelin off the east coast of Newfoundland and Labrador (NAFO Divisions 2J3KL) were conducted by Canada from 1981-1996 (Miller 1997), and by Russia from 1974-1993 (Bakanev & Sergeeva 1994). Biomass estimates of capelin from acoustic survey data declined dramatically in the early 1990s and the reason for this decline was never fully explained (Carscadden & Nakashima 1997). Canadian acoustic surveys in 2J3K were discontinued after 1994, although a spring survey in 3KL was conducted in 1996 (Miller 1997). Currently, capelin abundance is monitored offshore only through bottom-trawl by-catch (Lilly 1999), and pelagic juvenile fish surveys (Anderson *et al.* 1999). Both these methods target a relatively narrow depth range and there are potential biases in abundance estimates due to the vertical migration behaviour of capelin (e.g. O'Driscoll & Rose 1999) and trawl catchability (O'Driscoll *et al.* 2000.).

The pelagic juvenile trawl survey has been conducted annually every fall (August-September) since 1994. The survey design consists of a systematic grid of trawl stations at 30 nautical mile (nmi) intervals from southern Labrador to the southern Grand Banks. Since 1997, acoustic data (Simrad EK500) have been collected during the 30 nmi legs between trawl stations. In 1997 and 1998 only processed acoustic data (see Methods) was recorded and potential for analysis and interpretation of these data was limited. In 1999 we investigated the possibility of collecting high-resolution acoustic data on capelin distribution and abundance during the pelagic juvenile survey.

In this paper we present the results from our 1999 survey and compare these to observations on capelin distribution and abundance from 1997-1998 and to results from Canadian fall acoustic surveys for capelin in 1981-1994. We include acoustic estimates of offshore capelin biomass in 2J3K in 1998 and 1999. We also evaluate the potential for a future combined trawl/acoustic survey.

Methods

Acoustic data collection

The survey design is described in detail by Anderson & Dalley (1997). Surveys were conducted using two vessels (CCGS Teleost and CCGS Wilfred Templeman) from 11 August to 29 September 1997, from August 24 to September 10 1998, and from August 23 to September 17 1999. Acoustic data were collected on CCGS Teleost in 1997 and on both ships in 1998 and 1999. Only acoustic data collected on CCGS Teleost in 1997-1999 are considered in this paper. In all years CCGS Teleost covered the northern part of the survey area (2J3K) where capelin abundance was highest. Acoustic data from CCGS W. Templeman in 1998 are not presented because of concerns about calibration of the echo-sounder. Due to a vessel breakdown in 1999, CCGS W. Templeman only covered the very southern part of the survey area where no capelin were detected.

In 1997-1998 innermost trawl stations were visited on short east-west lines from south to north, and stations further offshore were visited in the same manner from south to north (Figs. 1-2). To enable easier analysis of acoustic data, in 1999 stations were visited sequentially in an east-west transect design (Fig. 3). Only acoustic data from the 30 nmi legs between trawl stations are presented in this paper. Acoustic data were also collected during IYGPT fishing sets to examine trawl catchability. The results of these experiments are summarised by O'Driscoll *et al.* (2000).

Acoustic data were collected on CCGS Teleost using a calibrated Simrad EK500 echo-sounder with a hull-mounted split-beam 38-kHz transducer. In 1997-1998 acoustic data was integrated by the echo-sounder in real-time into eight vertical bins (14-20 m, -75 dB integration threshold; 20-40 m, -75 dB; 40-60 m, -75 dB; 60-100 m, -73 dB; 100-150 m, -66 dB; 150-200 m, -60 dB; 200-250 m, -53 dB; 250-300 m, -47 dB). Integrated data were saved to a file every 5 min (1850 m at vessel speed 12 knots). Data output was in the form of average nautical area scattering (s_A = m^2/nmi^2) for each vertical bin over the preceding 5-min interval. In 1999 raw high-resolution acoustic data (volume backscattering strengths or S_v) were recorded using the custom-designed CH1 acquisition software (Simard et al. 1998). A summary of data acquisition parameters is provided

in Table 1. To decrease interference due to vessel noise maximum speed between trawl stations was reduced from 12-13 knots to 10 knots in 1999.

Acoustic data processing

We distinguished acoustic signals from capelin based on echogram appearance and information from IYGPT fishing sets conducted at trawl stations. IYGPT trawls at stations only sampled between 20 and 60 m depth. In 1999 one targeted IYGPT set was also made between stations to confirm identification of a deep concentration of capelin signal off southern Labrador.

In 1997 and 1998 integrated acoustic data from vertical bins identified as containing capelin were summed to give an estimate of average area scattering due to capelin in each 1850 m (5-min) horizontal bin. Area scattering (S_A) was calculated by converting Simrad output (s_A) to standard units (m^2/m^2) by dividing by $(1852\ m/nmi)^2$. Note that all acoustic terminology follows recommendations made at the ICES-FAST Working Group (MacLennan & Fernandes 1999).

Unrealistically high integration thresholds (>-70 dB) were applied to data collected at depths greater than 100m in 1997-1998. As a result some portion of the acoustic scattering due to capelin would not be integrated, biasing estimated fish densities downwards. To estimate the extent of the bias introduced by the high integration thresholds in 1997-1998 we integrated examples of capelin signal from 1999 using integration thresholds of -80 -75, -73, -66, -60, -53 and -47 dB (Table 2). This experiment revealed that over all depths abundance of capelin would be underestimated by a factor of approximately 0.66. At depths greater than 200 m the integration thresholds were so high (> -53 dB) that almost no capelin signal would be integrated. Fortunately few capelin were observed at depths greater than 200 m in 1997 or 1998 (Table 2). Note that we were still able to recognise capelin signal at all depths, because the printing threshold for the paper record was lower (-70 dB) than most of the integration thresholds. We used the correction factors in Table 2 to scale vertically binned s_A values from 1997-1998 prior to summation so the average area scattering was equivalent to that obtained by integrating at -80 dB.

In 1999 raw acoustic data were processed using CH2 data analysis software (Simard *et al.* 1998). An integration threshold of -80 dB was applied. Calculations showed that even a single small (<100 mm) capelin in the sampled volume would exceed this threshold at the range of depths commonly encountered in this survey (<300 m), while most other (biological and non-biological) "noise" would be filtered out. Signal identified as capelin was integrated throughout the water column in 100-m horizontal bins. The output of CH2 integration is average area backscattering (S_a). This was converted to average area scattering (S_A) by multiplying by 4π.

Mean capelin density (d) in each horizontal bin is calculated as:

$$d = \frac{S_A}{\sigma} \qquad (1)$$

where σ is the average acoustic cross-section. σ is related to target strength (TS) by the equation:

$$TS = 10\log_{10}\left(\frac{\sigma}{4\pi}\right) \qquad (2)$$

We used two estimates of capelin target strength. For comparison with previous Canadian acoustic surveys (Miller & Lilly 1991, Miller 1997) we scaled S_A by a TS of -34 dB kg^{-1}. We also used the length-scaled TS relationship for capelin of $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). Capelin length-frequency data were obtained from fishing sets.

Biomass estimation

Two methods were used to estimate capelin biomass. *Method 1* was designed to provide biomass estimates for NAFO 2J3K which were directly comparable with those obtained in previous Canadian fall acoustic surveys. *Method 1* was applied to data from 1998 and 1999. We did not attempt to estimate biomass in 1997 because not all lines in 2J3K were surveyed acoustically. *Method 2* provides what we believe is the "best" estimate of capelin biomass from the 1999 survey.

Method 1

The northern part of the survey area (in NAFO 2J3K) was divided into nine blocks corresponding to nine east-west transects (Figs 2-3). Blocks were 56 km wide (30 nmi) and between 190 and 280 km long. A single transect passed through the centre of each block. Capelin biomass was estimated independently for each block from the equation:

$$B_i = A_i \bar{d}_i \qquad (3)$$

where B_i is the biomass of capelin in block i (kg)
A_i is the area of block i (m^2)
$\bar{d}_i$ is the mean capelin density in block i (kg m^{-2})

Using equations (1) and (2) $\bar{d}_i$ was estimated from binned S_A values using a TS of -34 dB kg^{-1} (σ = 0.005 m^2/kg) (Miller 1997). This estimate assumes constant TS over all lengths and weights of capelin.

In 1998 S_A values were integrated in 1850-m horizontal bins. There was seldom autocorrelation between consecutive non-zero bins within a block, so 1850-m bins were treated as independent sample estimators of capelin density (d_i). 95% confidence intervals were defined as $\bar{d}_i$ +/- 1.96 standard errors (Table 3). To illustrate the effect on biomass of the correction for high integration thresholds (Table 2), we also calculated capelin biomass for 1998 using the uncorrected data (Table 4).

In 1999 S_A values were integrated in 100-m bins. These data were highly autocorrelated so to estimate sampling uncertainty we used a bootstrapping method (Robotham & Castillo 1990). We repeatedly (100 times) took a random sample of 5% of the 100-m binned data from each block. There was usually no significant autocorrelation in the 5% sampled data. The 100 sample means were used to calculate the bootstrapped mean density ($\bar{d}_i$) and 95% confidence intervals for each block (Table 5).

Total capelin biomass in 2J3K was calculated as the sum of the biomass in the nine blocks (Tables 3-5).

Method 2

We post-stratified the survey area into six strata (Fig. 4) based on the observed capelin distribution and length-frequency data from fishing sets (Table 6).

Capelin biomass in each stratum was calculated from the equation:

$$B_i = w_i A_i \overline{D}_i \qquad (4)$$

where B_i is the biomass of capelin in stratum i (kg)

w_i is the average weight of capelin from fishing sets in stratum i (kg)

A_i is the area of stratum i (m^2)

$\overline{D}_i$ is the mean fish density of capelin in stratum i (fish m^{-2})

$\overline{D}_i$ was estimated from 100-m binned S_A values using the length-scaled *TS* relationship for capelin of $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). Capelin length-frequency data were obtained from fishing sets in each stratum (Table 6).

To estimate sampling uncertainty we again used a bootstrapping method (Robotham & Castillo 1990) for each stratum based on repeated 5% sampling of the 100-m binned data (100 times). The 100 sample means were used to calculate the bootstrapped mean density ($\overline{D}_i$) and 95% confidence intervals for each stratum (Table 7).

Results

Capelin were readily identified in the northern part of the pelagic juvenile survey area (north of ~48.5° N). In this region capelin were the dominant acoustic scatterer in water <300 m deep. Arctic cod (*Boreogadus saida*) and shrimp (*Pandalus* spp.) were also present, but were distinguished from capelin based on *TS* (higher than capelin for arctic cod, lower for shrimp) and aggregation structure. A deep scattering layer comprised mainly of euphausiids and myctophids (our unpublished data) was associated with the shelf break in water >350 m. In 1999 the Teleost survey extended further south (Fig. 3). On the Grand Banks south of 48.5° N relatively low numbers of small capelin were commonly associated with large concentrations of sandlance (*Ammodytes* spp.). During the day it was

sometimes possible to distinguish capelin and sandlance based on differences in school structure. At night, however, both capelin and sandlance formed a homogeneous layer near the surface and could not be distinguished acoustically. When this occurred we partitioned acoustic scattering due to capelin and sandlance based on IYGPT trawl catches and specific length-based *TS* values. For example, one IYGPT set on the mixed layer caught 11,000 sandlance with mean length 11cm and 1000 capelin mean length 10 cm. The *TS* of an 11 cm sandlance was calculated from the equation $TS = 20\log L - 83$ (George Rose pers. comm.) as -62.2 dB ($\sigma = 7.62 * 10^{-6}$ m^2). Similarly, *TS* of an 10 cm capelin was calculated from the equation $TS = 20\log L - 73.1$ (Rose 1998) as -53.1 dB ($\sigma = 6.15 * 10^{-5}$ m^2). Based on the trawl catch composition the proportion of the total acoustic scattering due to capelin ($S_{A capelin}$) = $1000(6.15 * 10^{-5}) / (1000(6.15 * 10^{-5}) + 11,000(7.62 * 10^{-6})) = 0.42$.

There was a northward shift in the spatial distribution of capelin between 1997 and 1999 (Figs. 1-3). Very few capelin were observed in 1997, with the exception of a very large concentration off Bonavista Bay (Fig. 1). In 1998 highest densities of capelin were detected off St. Anthony, with smaller aggregations north of Fogo Island, on outer Funk Island Bank and in the Bonavista corridor (Fig. 2). Capelin were further north again in 1999, with peak densities off southern Labrador. Concentrations of capelin were also detected on outer Funk Island Bank, on the Northeast Grand Banks and in Conception Bay in 1999 (Fig. 3).

There was general agreement between regions of high acoustic density and IYGPT trawl catches (Fig. 5). However, the concentration of capelin detected acoustically off Belle Isle and southern Labrador in 1999 (Fig. 3) remained close to the bottom and IYGPT trawls at stations in this area caught few capelin (Fig. 5). A targeted IYGPT trawl at 190 m depth confirmed that the acoustic signal was capelin.

Using a capelin *TS* of -34 dB kg^{-1} (c.f. Miller 1997) we estimated capelin biomass in 2J3K as 86,000 tons (95% confidence interval 36,000-135,000 tons) in 1998 (Table 3) and 69,000 tons (33,000-116,000 tons) in 1999 (Table 5). Note that these estimates do not include the inshore bays or areas of 2J3K to the north and east beyond the survey boundaries (Figs 2-3). Estimates of capelin biomass in 2J3K

in 1998 and 1999 were similar to estimates from Canadian fall acoustic surveys in the early 1990s and lower than all estimates from 1981-1990 (Fig. 6).

Without the correction for depth-variable integration thresholds (Table 2), capelin biomass in 1998 data was estimated as 55,000 tons (23,000-87,000 tons) (Table 4), or 64% of the corrected biomass (Table 3).

Figure 6 provides a relative index of capelin abundance based on scaled S_A values. However, a more recent model of capelin *TS* (Rose 1998) suggests that a *TS* of -34 dB kg^{-1} will overestimate absolute abundance. We derived a length-weight relationship for capelin from measurements on fish captured during our 1999 survey (W (g) = $4.7361*10^{-8}$ L $(mm)^{3.9248}$, n = 468, r^2 = 0.95) Using this relationship we calculated capelin *TS* in dB kg^{-1} using the length based model of Rose (1998), and also a model by the same author which incorporates both length and weight (Fig. 7). Figure 7 shows that a *TS* of -34 dB kg^{-1} is only appropriate for large capelin (~180 mm). Smaller capelin, like those observed in our surveys, have a much higher *TS* per kg (-26 or -28 dB kg^{-1} depending on choice of model). Estimates of abundance based on *TS* -34 dB kg^{-1} will therefore overestimate abundance of smaller capelin by as much as a factor of four.

There was considerable geographical variation in size composition of capelin catches during the 1999 survey (Table 6, Fig. 8). Capelin from the targeted trawl in southern Labrador were larger and older (Fig. 8) than fish from other areas. Capelin from Funk Island Bank stations were also larger than capelin from the Grand Banks, Conception Bay and the inshore. Almost all capelin captured at trawl stations were one-year olds (Fig. 8).

Total survey biomass estimated using *Method 2* was 43,000 tons (27,000-61,000 tons) of capelin (Table 5). The discrepancy between this estimate and the much higher estimates for 2J3K from *Method 1*is due solely to the choice of a length-scaled *TS* model in *Method 2*. If we apply a *TS* of -34 dB kg^{-1} to the stratified survey area, total biomass was 94,000 tons (60,000-131,000 tons).

Discussion

The pelagic juvenile survey provides a cost-effective platform to conduct acoustic research on capelin distribution and abundance in Newfoundland waters. High quality acoustic data were collected in 1999 with little cost to the existing survey in terms of personnel (one additional scientist on each ship) or time (slight reduction in cruising speed). Acquisition and processing of acoustic data from the hull-mounted EK500 using CH1 and CH2 was straightforward. The coverage of the survey is extensive and includes much of the range of capelin over the Newfoundland shelf (2J3KLNO).

The major limitation of a combined pelagic trawl/acoustic survey is identification and sampling of acoustically detected capelin. Although an experienced observer is able to recognise capelin acoustic signal based on signal characteristics, it is necessary to "ground truth" subjective classifications with targeted fishing sets. Targeted fishing sets are also required to provide accurate age-composition data on capelin concentrations. We did not attempt to provide an age-structured estimate of capelin biomass in this paper because almost all of our length and age data came from standard tows on station. These shallow (20-60 m) tows were dominated by one-year old capelin. A single targeted deep set in 1999 caught a wider age range of capelin suggesting that there may be vertical segregation of ages, with larger older fish occurring below the zone sampled during pelagic juvenile tows.

Capelin exhibit variable vertical migration behaviour. Characteristically capelin are in layers near the surface at night and form schools in midwater and close to the bottom during the day. However there are interannual (Shackell *et al.* 1994) and seasonal (O'Driscoll & Rose 1999) variations in this general pattern. There may also be spatial variation in vertical distribution. In August-September 1999 the distribution of capelin in most areas was consistent with the general diurnal vertical migration model (Fig. 9). However, the major concentration of capelin off southern Labrador and Belle Isle did not appear to vertically migrate. Capelin in these areas were close to the bottom during the day and night (Fig. 9). Such near-bottom concentrations of capelin will not be caught by

the standard surface tows of the pelagic survey and can only be sampled by targeted trawling.

In future combined trawl/acoustic surveys time should be built into the survey design to allow between 5-10 targeted trawls on capelin concentrations detected acoustically which are between stations or deeper than the pelagic zone sampled on stations. Alternatively a two-stage design might be implemented, where concentrations of capelin detected during the pelagic juvenile survey are revisited and sampled more extensively by a short dedicated capelin acoustic survey following the pelagic juvenile cruise.

The northward shift in the distribution of capelin we observed from 1997 to 1999 is consistent with the trend in the distribution of capelin catches from fall (October to December) bottom-trawl surveys (Lilly 1999). In 1998 large catches of capelin were made further north than in 1997 (Lilly 1999) and this northward trend seems to have continued in 1999 (George Lilly pers. comm.). Independent acoustic surveys for cod in the Hawke Channel area of southern Labrador have been conducted from June 1994-1999. Capelin were detected in these surveys for the first time in 1998. In June 1999 the abundance of capelin around Hawke Channel was at least an order of magnitude higher than in 1998 (O'Driscoll & George Rose unpublished data).

During the early 1990s the spatial distribution of capelin in NAFO 2J3KL changed dramatically (review by Carscadden & Nakashima 1997). Acoustic surveys, bottom-trawl surveys and cod-stomach-content analysis all showed a shift in the distribution of capelin towards the south and east. Capelin virtually disappeared from the northern part of their range, and the centre of the concentration of maturing fish shifted from NAFO 2J to southern 3K and 3L (Carscadden & Nakashima 1997). At the same time capelin increased in areas such as the Flemish Cap and Scotian Shelf where they were not common previously (Frank *et al.* 1996). Observations of a more northerly offshore distribution of capelin in 1998-1999 suggest that capelin are returning to historical distribution patterns.

Capelin biomass offshore in 2J3K in 1998 and 1999 was low compared to levels observed during the Canadian fall acoustic surveys in the 1980s and similar to abundance observed following the dramatic decline in the early 1990s.

Carscadden & Nakashima (1997) suggest that acoustic surveys in the early 1990s underestimated capelin abundance because of changes in the distribution and behaviour of the fish. For example, there was independent evidence from spring acoustic surveys for cod that capelin density on parts of the outer northeast Newfoundland shelf remained high from 1990-1994 (O'Driscoll & Rose submitted).

In light of our low acoustic estimates of abundance in 1998-1999 we believe it is worthwhile to consider the influence of fish distribution and behaviour on acoustic estimates of biomass. We also discuss sources of error associated with survey methodology.

The biomass estimates presented in this paper are estimates of capelin abundance in the surveyed area only. We did not extrapolate beyond the survey boundaries. The major influence of capelin distribution on estimated biomass will therefore be related to the proportion of total capelin in the surveyed area. The coverage of the pelagic juvenile survey is extensive, but there was evidence from our 1998 and 1999 surveys that transects did not extend far enough east to fully map the offshore distribution of capelin, particularly on Funk Island Bank and the northeast Grand Banks. In 1998 and 1999 capelin densities were high round the outermost stations on Funk Island Bank in blocks d and e. In 1999 we also observed relatively high densities of capelin at the outermost stations on the northern Grand Banks. It would be desirable to extend all transects east at least as far as the 500 m contour to determine the extent of these capelin aggregations.

Few capelin were detected on the northernmost transects in 1997-1999 suggesting that the pelagic juvenile survey area extended beyond the northern boundary of the capelin distribution in these years. The fall groundfish surveys in 1997 and 1998 caught few capelin north of 53°N (Lilly 1999). In the 1980s high concentrations of capelin were commonly observed on Hamilton Bank (Miller & Lilly 1991). If the northward shift in the distribution of capelin continues it may be necessary to extend the pelagic juvenile survey further north to cover this region.

The inshore coverage of the pelagic juvenile survey is limited. Typically trawl stations and acoustic transects surveyed the central portion of the major bays only. We

re-emphasize that the abundance estimates in this paper reflect the surveyed area only. We did not have adequate coverage to accurately assess capelin abundance inshore. Some capelin occur in the large bays of the northeastern Newfoundland coast year-round (Winters 1969), but is uncertain how much these "coastal capelin" (Winters 1969) contribute to the total capelin biomass. We observed relatively high densities of capelin inshore on other acoustic surveys in January, May and June of 1999 suggesting that there may be significant concentrations of capelin in the bays at these times. Further work is necessary to quantify the relative importance of the inshore and offshore areas to capelin. The existence of concentrations of capelin which remain inshore, especially in Trinity Bay where most estimates of inshore abundance are carried out, might help to explain the apparent discrepancy between views of the stock based on beach spawning and offshore estimates of capelin abundance.

Carscadden & Nakashima (1997) hypothesised that capelin in the early 1990s may have been "undetectable by the acoustic gear because they were scattered rather than in schools" (p 466). Calculations based on the sampled acoustic volume showed that even individual small capelin would be detected and included in the integration at a threshold of -80dB. The issue is not one of detection but rather of recognition. Because capelin signal was classified subjectively, there is potential for an observer to fail to recognise low densities of capelin amongst the other sources of biological scattering. This *recognition threshold* accounts for the small catches of capelin sometimes made when no recognisable capelin signal is identified acoustically (O'Driscoll *et al.* 2000.).

We attempted to quantify the magnitude of bias in the biomass estimate introduced by the recognition threshold by comparing IYGPT trawl catches with acoustic estimates of capelin in the 20-60 m trawl zone (see O'Driscoll *et al.* 2000. for details). There were a total of 64 IYGPT sets in 1999 where no capelin were recognised acoustically in the 20-60 m trawl zone. In these 64 sets an average of 11.75 capelin were captured (range 0-175 capelin per set). This is equivalent to an average density of capelin of $8.16 * 10^{-5}$ fish m^{-3} if we assume trawl catchability equals 1 at low capelin densities. The average depth of the surveyed area was 224 m, so the estimated recognition threshold is equivalent to an areal density of capelin of 0.0183 fish m^{-2}

if the same low densities of capelin occurred throughout the water column. For the survey area of 196 billion m^2 this threshold equates to 3.6 billion capelin. Average individual weight of capelin was 3.18 g, so the estimated biomass of capelin not detected acoustically due to the recognition threshold was ~11,400 tons or 26% of the total biomass in 1999 (Table 7). This was well within the range of the sampling uncertainty.

Other potential sources of error related to capelin behaviour include boat avoidance, surface and bottom acoustic dead-zones, and acoustic shadowing. Capelin close to the surface (< 15 m depth) or to the bottom (< 0.5 m above bottom depending on depth) could not be detected acoustically by our equipment. Additionally capelin close to the surface may avoid the vessel. At very high fish densities S_A is not proportional to fish density because fish nearest the transducer attenuate the echo energy so that it cannot penetrate to the more distant fish (MacLennan & Simmonds 1992). We were not able to quantify the magnitude of these sources of bias, but it is generally accepted that capelin are ideal acoustic targets because they seldom distributed too close to the surface or to the bottom and they do not form very dense schools (Toresen *et al.* 1998).

A major source of uncertainty in the acoustic estimate of capelin biomass is acoustic target strength (*TS*). We have shown that total survey biomass in 1999 is more than doubled if we use a *TS* of -34 dB kg^{-1} instead of the length-scaled model of Rose (1998). Surveys for capelin in the Barents Sea use a third model of *TS* (Toresen *et al.* 1998). The Norwegian model is length-scaled by the relationship $TS = 19.1 \log L - 74.0$. Capelin biomass obtained using the Norwegian *TS* model for our 1999 survey and *Method 2* was 67,000 tons (42,000-94,000 tons). This is higher than the estimate using the Rose (1998) model (43,000 tons), but lower than estimate obtained using -34 dB kg^{-1}. Further *in situ* measurements of *TS* are required to compare to existing models. Length-based *TS* models also require better information about the size composition of the capelin contributing to the scattering from targeted fishing sets.

Capelin are a key component of the northwest Atlantic ecosystem and a key prey species of many economically important species such as Atlantic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*) and harp seals (*Phoca*

groenlandica). Given this importance, we feel it is imperative for continued research on capelin abundance and distribution in Newfoundland waters. Research is especially important in the next few years, as there is continued evidence of changing ecosystem dynamics. Despite the limitations described we believe acoustics is the best method to quantify capelin abundance. Capelin can be detected throughout much of the water column, avoiding problems associated with vertical distribution and catchability that affect estimates based on trawl surveys (e.g. Anderson *et al.* 1999). We hope that the data presented in this paper form the basis for a time series of offshore capelin abundance from continued pelagic trawl/acoustic surveys.

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References

Anderson, J.T. and Dalley, E.L. 1997. Spawning and year-class strength of northern cod (*Gadus morhua*) as measured by pelagic juvenile cod surveys, 1991-1994. Can. J. Fish. Aq. Sci. 54(Suppl. 1): 158-167.

Anderson, J.T., Dalley, E.L. and Carscadden, J.E. 1999. Absolute abundance and biomass of juvenile and adult capelin (*Mallotus villosus*) in the Newfoundland region (2J3KLNO) estimated from the pelagic juvenile fish surveys, 1994-1998. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206 pp ???

Bakanev, V. S. and Sergeeva, T. M. 1994. Results of acoustic survey for capelin (*Mallotus villosus*) in NAFO divisions 3LNO in 1993. NAFO Sci. Coun. Res. Doc. 94/14 5pp.

Carscadden, J., and Nakashima, B.S. 1997. Abundance and changes in distribution, biology, and behavior of capelin in response to cooler waters of the 1990s. *In* Forage fishes in marine ecosystems. Lowell Wakefield

Symposium Series. University of Alaska Sea Grant College Program, Fairbanks, Alaska pp. 457-468.

Frank, K.T., Carscadden, J.E. and Simon, J.E. 1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. Can. J. Fish. Aq. Sci. 53: 1473-1486.

Lilly, G.R. 1999. By-catches of capelin during spring and autumn bottom-trawl surveys in Divisions 2J3KL in 1998. *In* Capelin in SA2 + Div. 3KL CSAS Res. Doc. 99/206 pp ?????

MacLennan, D.N. and Simmonds, E.J. 1992. Fisheries acoustics. Chapman and Hall, London.

MacLennan, D.N. and Fernandes, P.G. 1999. Acoustical definitions, units and symbols. ICES-FAST Working Group Report. St. John's, Newfoundland April 1999. 8pp.

Miller, D.S. 1995. Results from an acoustic survey for capelin (*Mallotus villosus*) in NAFO Divisions 2J3KL in the autumn of 1994. *In* Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70: 63-71.

Miller, D.S. 1997. Results from an acoustic survey for capelin (*Mallotus villosus*) in NAFO Divisions 3KL in the spring of 1996. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 97/29 pp 84-90.

Miller, D.S. and Lilly, G.R. 1991. Observations and studies on SA2 + Div. 3K capelin in 1990. CAFSAC Res. Doc. 91/11 27pp.

O'Driscoll, R.L. and Rose, G.A. 1999. Seasonal changes in abundance, distribution and vertical migration of capelin in Placentia Bay. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206 pp???

O'Driscoll, R.L. and Rose, G.A. (submitted). Spatial dynamics of cod-capelin associations off Newfoundland. *In* Spatial processes and management of fish populations. Lowell Wakefield Symposium Series. University of Alaska Sea Grant College Program, Fairbanks, Alaska.

O'Driscoll, R.L., Rose, G.A. and Anderson, J.T. 2000. Relationship between acoustic estimates of capelin and trawl catches in Campelen and IYGPT trawls. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 2000/?? pp???

Robotham, H. and Castillo, J. 1990. The bootstrap method: an alternative for estimating confidence intervals of resources surveyed by hydroacoustic techniques. Rapp. P.-v. Reun. Cons. int. Explor. Mer 189: 421-424.

Rose, G.A. 1998. Acoustic target strength of capelin in Newfoundland waters. ICES J. Mar. Sci. 55: 918-923.

Shackell, N.L., Carscadden, J.E. and Miller, D.S. 1994. Diel vertical migration of capelin (*Mallotus villosus*) and its effect on acoustic estimates of density. ICES Coun. Meeting Rep. 1994/Mini:5 18pp.

Simard, Y., McQuinn, I., Montminy, M., Samson, Y., Lang, C., Stevens, C. and Miller, D. 1998. CH1, Canadian hydroacoustic data analysis tool 1 user's manual, (version 2.0). Can. Tech. Rep. Fish. Aq. Sci. 2256 100pp.

Toresen, R., Gjosaeter, H. and de Barros, P. 1998. The acoustic method as used in the abundance estimation of capelin (*Mallotus villosus* Muller) and herring (*Clupea harengus* Linne) in the Barents Sea. Fish. Res. 34: 27-37.

Winters, G. H. 1969. Migrations of coastal capelin in Trinity Bay. Fish. Res. Bd. Can. St. John's Biol. Stn. Circ. 16: 10-11.

Table 1. Specifications for EK500 on Teleost surveys in August-September 1998 and 1999.

	1998	1999
Frequency	38kHz	38kHz
Ping Interval	1s	1s (250m range) 1.5s (400m) 2s (500m)
Pulse length	1.0ms	1.0ms
Bandwidth	3.8kHz	3.8kHz
Transmit Power	2000W	2000W
Absorption Coefficient	10dB km^{-1}	10dB km^{-1}
2-Way Beam Angle	-20.6 dB	-20.6 dB
Sv Transducer Gain	25.60 dB	25.77 dB
TS Transducer Gain	25.60 dB	26.00 dB
TVG	20logR	20logR
Angle Sensitivity Along.	21.9	21.9
Angle Sensitivity Athw.	21.9	21.9
3 dB Beamwidth Along.	7.1 dg	7.0 dg
3 dB Beamwidth Athw.	7.1 dg	6.8 dg
Along. Ship Offset	0.00 dg	-0.16 dg
Athw. Ship Offset	0.00 dg	-0.16 dg
Range of Raw Sv data collection	none	250m, 400m or 500m
Vertical Sampling Resolution	6-50m (see text)	0.1m
Bottom Removal	internal Simrad algorithm	none on raw data
Vessel Speed	~12 knots	10 knots

Table 2. Effect of depth-variable integration thresholds used in 1997 and 1998 on estimates of capelin density. Correction factors were obtained empirically using data from 1999 and are expressed as the proportion of (area scattering due to capelin calculated with integration threshold *x*) / (area scattering calculated with an integration threshold of –80 dB). Table also shows the percentage of total capelin observed in each vertical bin in 1997 and 1998.

Vertical Bin	Integration Threshold	Correction Factor	Percentage Capelin 1997	Percentage Capelin1998
14-20m	-75	0.92	14	5
20-40m	-75	0.92	17	14
40-60m	-75	0.92	11	14
60-100m	-73	0.87	14	23
100-150m	-66	0.56	20	25
150-200m	-60	0.21	18	11
200-250m	-53	0.02	5	5
250-300m	-47	0.00	1	3

Table 3. Capelin biomass estimate for NAFO 2J3K from Teleost 69 survey August 24 to September 10 1998 using *Method 1* (TS = -34 dB kg^{-1}). Data were scaled by values in Table 2 to correct for bias due to high integration thresholds. See Fig. 2 for block boundaries. 95% confidence intervals are sample mean +/-1.96 standard errors.

Survey Block	No. of 1850-m bins	Mean capelin density g m^{-2} ($\overline{d}$,) (95% CI)	Transect area (*10^9 m^2)	Transect biomass (tons) (95% CI)
a	91	0.803 (0.464-1.141)	12.4	9917 (5739-14095)
b	100	1.494 (0.558-2.430)	12.4	18462 (6897-30027)
c	87	0.145 (0.058-0.232)	12.4	1788 (715-2861)
d	90	0.552 (0.280-0.824)	15.4	8522 (4320-12723)
e	118	2.281 (0.987-3.575)	15.4	35208 (15232-55184)
f	87	0.966 (0.283-1.650)	12.4	11942 (3498-20386)
g	89	0	13.9	0
h	73	0.004 (0.000-0.011)	10.7	39 (0-117)
i	104	0	10.7	0
Total	839		115	85878 (36402-135393)

Table 4. Uncorrected capelin biomass estimate for NAFO 2J3K from Teleost 69 survey August 24 to September 10 1998 using *Method 1* (TS = -34 dB kg^{-1}). No corrections for integration threshold were applied. See Fig. 2 for block boundaries. 95% confidence intervals are sample mean +/-1.96 standard errors.

Survey Block	No. of 1850-m bins	Mean capelin density g m^{-2} ($\overline{d_i}$) (95% CI)	Transect area ($*10^9$ m^2)	Transect biomass (tons) (95% CI)
a	91	0.582 (0.349-0.816)	12.4	7195 (4307-10083)
b	100	0.707 (0.252-1.163)	12.4	8741 (3115-14368)
c	87	0.057 (0.020-0.095)	12.4	709 (243-1176)
d	90	0.505 (0.256-0.755)	15.4	7799 (3944-11654)
e	118	1.816 (0.688-2.945)	15.4	28035 (10614-45457)
f	87	0.173 (0.025-0.321)	12.4	2136 (304-3967)
g	89	0	13.9	0
h	73	0.002 (0-0.002)	10.7	22 (0-65)
i	104	0	10.7	0
Total	839		115	54637 (22526-86770)

Table 5. Capelin biomass estimate for NAFO 2J3K from Teleost 81 survey August 23 to September 17 1999 using *Method 1* (TS = -34 dB kg^{-1}). See Fig. 3 for block boundaries. 95% confidence intervals are from 5% bootstrapping.

Survey Block	No. of 100-m bins	Mean capelin density g m^{-2} ($\overline{d_i}$) (95% CI)	Transect area ($*10^9$ m^2)	Transect biomass (tons) (95% CI)
a	2044	0.206 (0.058-0.549)	12.4	2540 (713-6778)
b	2179	0.377 (0.065-0.967)	12.4	4659 (805-11954)
c	1965	0.145 (0.047-0.340)	12.4	1794 (580-4207)
d	2482	0.766 (0.374-1.176)	15.4	11823 (5776-18152)
e	2498	0.186 (0.096-0.303)	15.4	2875 (1474-4674)
f	2162	2.031 (1.090-3.012)	12.4	25093 (13463-37217)
g	2276	1.460 (0.756-2.380)	13.9	20254 (10494-33025)
h	1634	0	10.7	0
i	1722	0	10.7	0
Total	18962		115	69038 (33305-116007)

Table 6. Capelin target strength calculated from length-frequency data for individual strata in fall 1999. See Fig. 4 for strata boundaries.

Stratum	Sample size	Mean σ (m^2)	Mean TS (dB)	Mean length (mm)	Mean weight (g)
LAB	206	1.28E-04	-49.9	144	14.6
FIB	640	9.62E-05	-51.2	125	8.7
NEGB	220	5.71E-05	-53.4	96	3.0
SGB	749	5.36E-05	-53.7	92	2.1
INS	981	5.01E-05	-54.0	89	3.4
CB	220	5.45E-05	-53.6	94	3.0

Table 7. Capelin abundance and biomass estimates from full Teleost 81 survey August 23 to September 17 1999 using *Method 2*. See Fig. 4 for strata boundaries. 95% confidence intervals are from 5% bootstrapping.

Stratum	No. of 100-m bins	Mean capelin density m^{-2} ($\overline{D}_i$) (95% CI)	Stratum area ($*10^9$ m^2)	Stratum abundance (billions) (95% CI)	Stratum biomass (tons) (95% CI)
LAB	7703	0.041 (0.026-0.059)	42.9	1.78 (1.13-2.53)	25924 (16471-36900)
FIB	5805	0.040 (0.024-0.058)	31.1	1.25 (0.74-1.79)	10888 (6460-15594)
NEGB	4265	0.045 (0.030-0.059)	25.0	1.13 (0.76-1.46)	3393 (2266-4391)
SGB	11700	0.013 (0.009-0.016)	52.4	0.67 (0.47-0.85)	1398 (988-1792)
INS	11995	0.006 (0.004-0.009)	43.9	0.29 (0.17-0.42)	968 (580-1410)
CB	722	0.156 (0.122-0.205)	1.0	0.16 (0.13-0.21)	485 (378-637)
Total	42190		196	5.27 (3.39-7.26)	43055 (27143-60724)

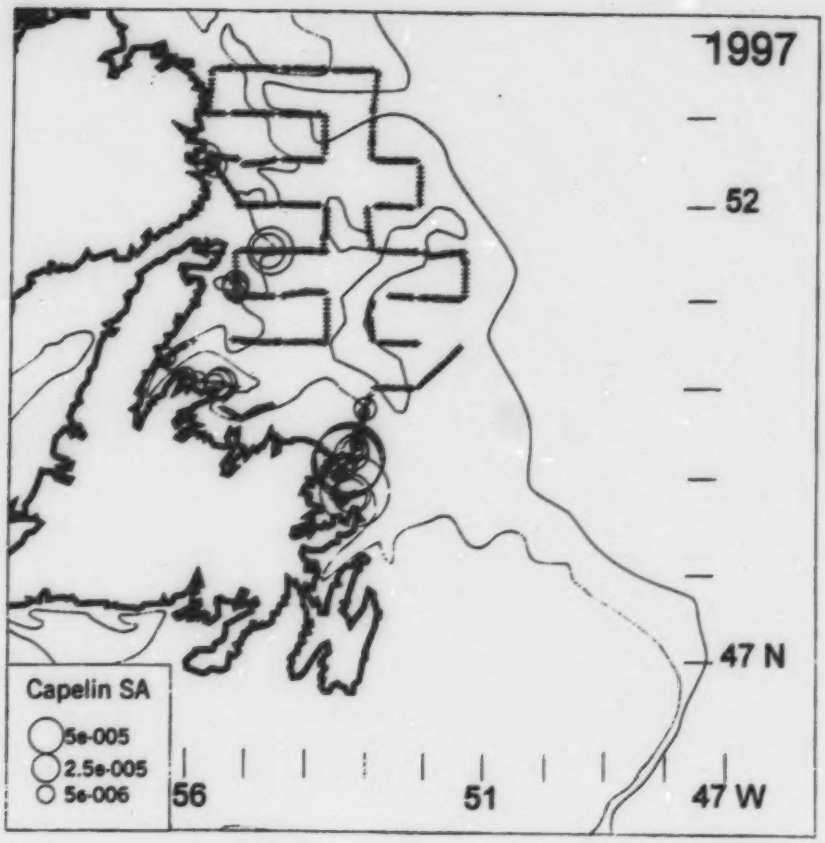

Fig. 1. Expanding symbol plot showing capelin distribution from fall 1997 pelagic juvenile survey. Acoustic data were corrected for depth-variable integration thresholds (Table 2) and averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours.

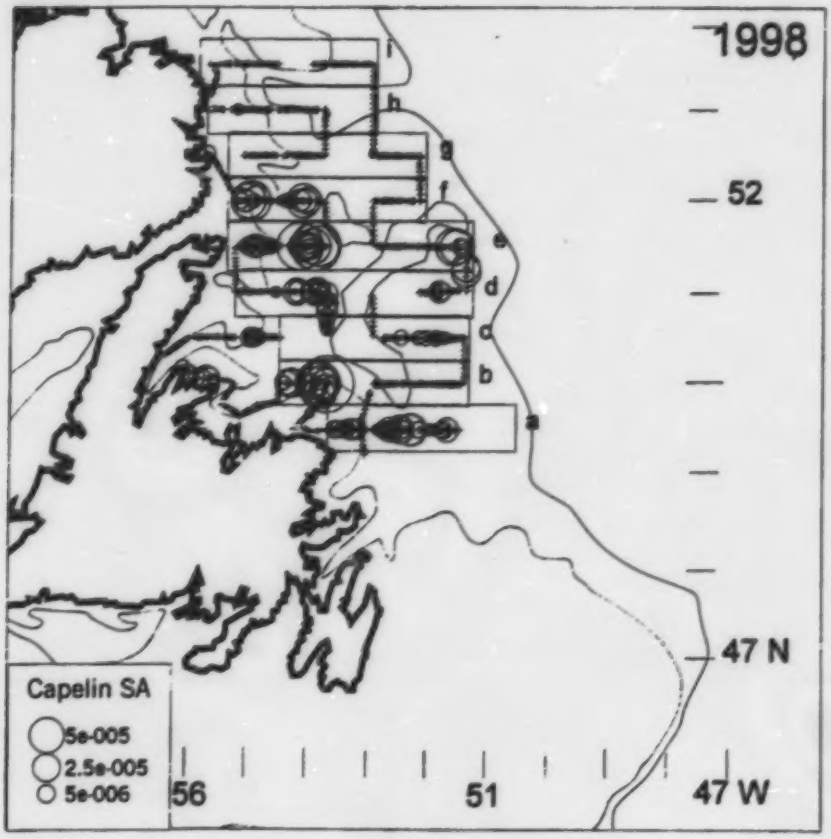

Fig. 2. Expanding symbol plot showing capelin distribution from fall 1998 pelagic juvenile survey. Acoustic data were corrected for depth-variable integration thresholds (Table 2) and averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours. Blocks used for estimating biomass in 2J3K (*Method 1*) are indicated and lettered.

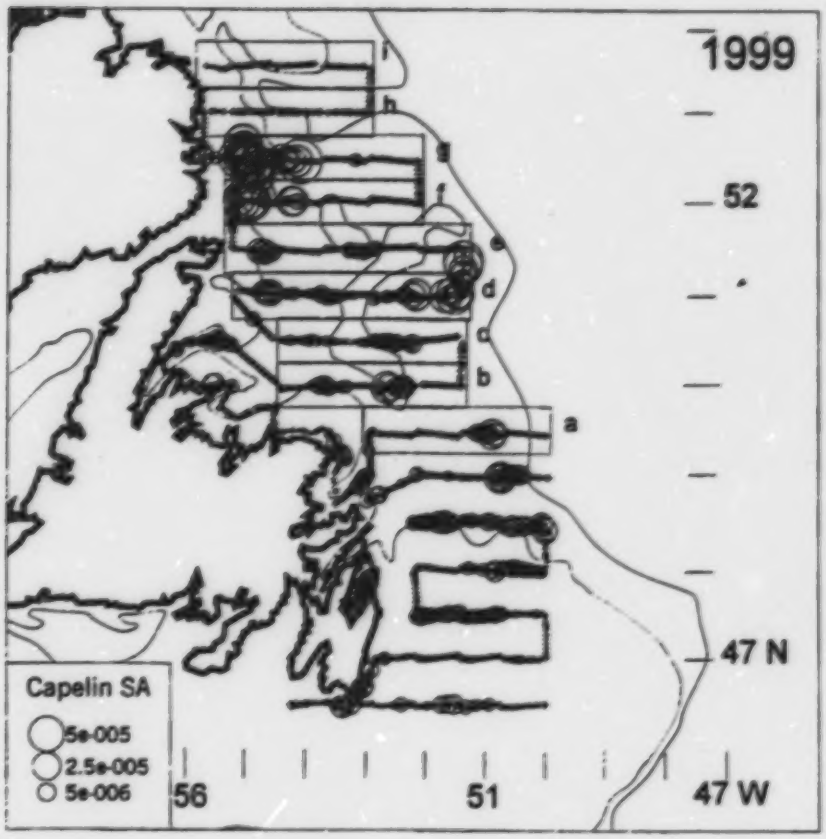

Fig. 3. Expanding symbol plot showing capelin distribution from fall 1999 pelagic juvenile survey. Acoustic data averaged into 5-km bins for display. '+' symbol indicates no capelin were detected in that bin. Bathymetry shows 200 m (dotted) and 500 m (solid) depth contours. Blocks used for estimating biomass in 2J3K (*Method 1*) are indicated and lettered.

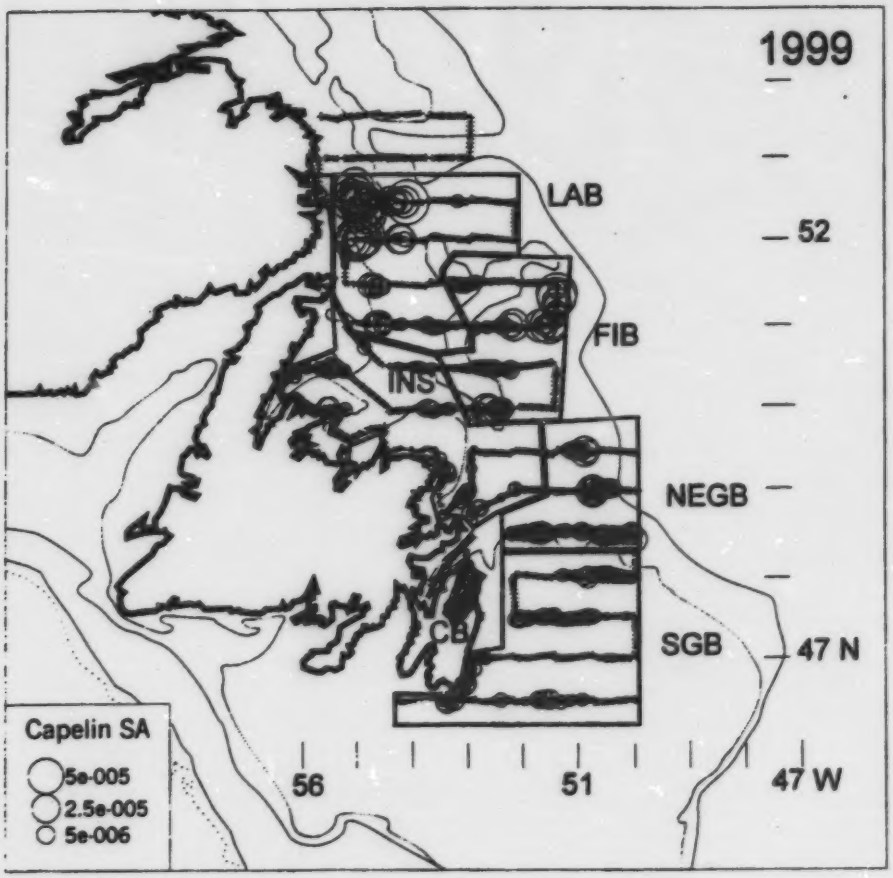

Fig. 4. Expanding symbol plot showing capelin distribution from fall 1999 pelagic juvenile survey and strata used to estimate total survey biomass (*Method 2*). See Fig. 3 for further details.

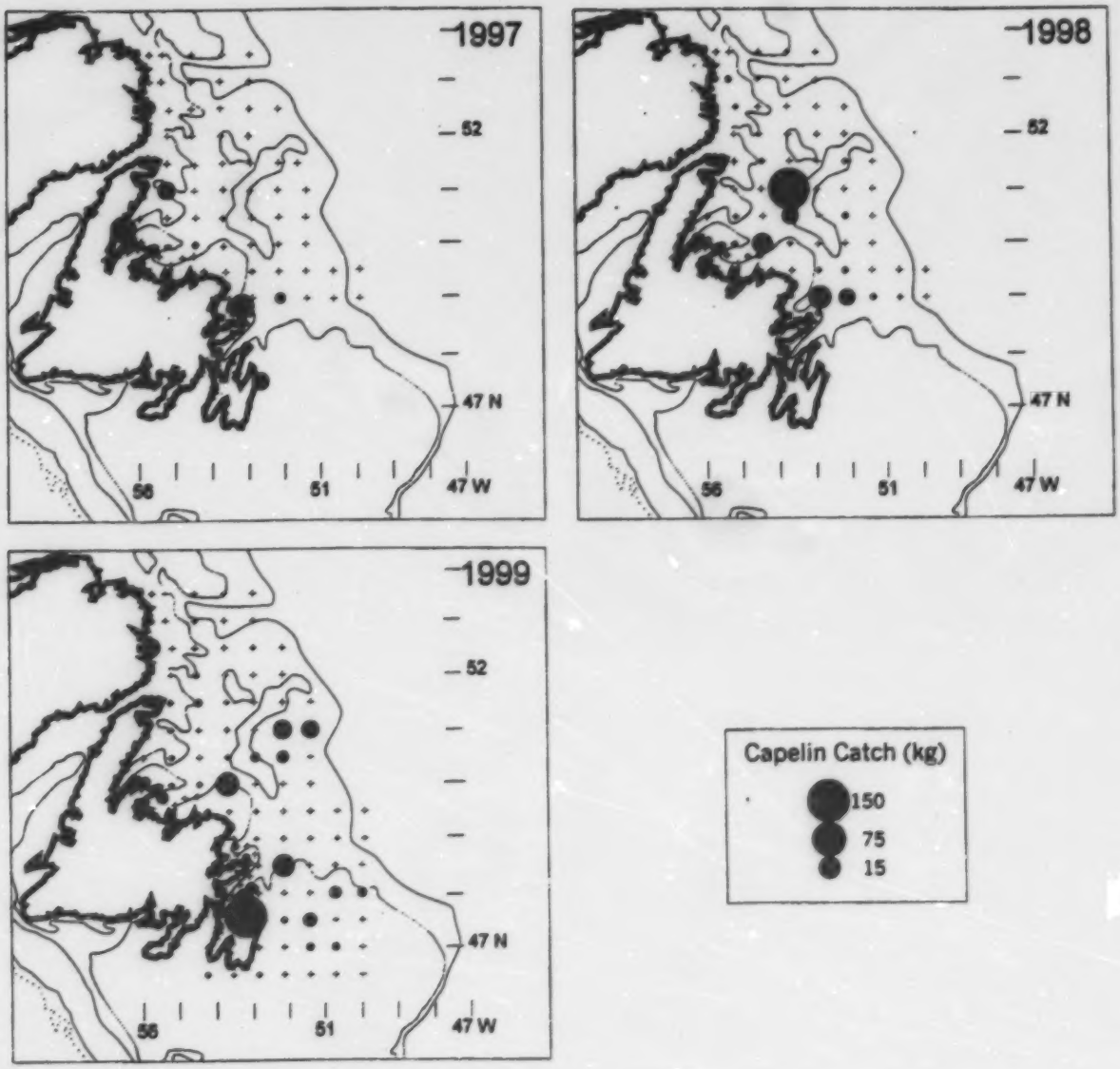

Fig. 5. Capelin catches in IYGPT trawls at 20-60 m depth during fall pelagic juvenile surveys 1997-1999. Circle size is proportional to catch. '+' symbol indicates no capelin were caught. Catches are not corrected for day-night differences in catchability.

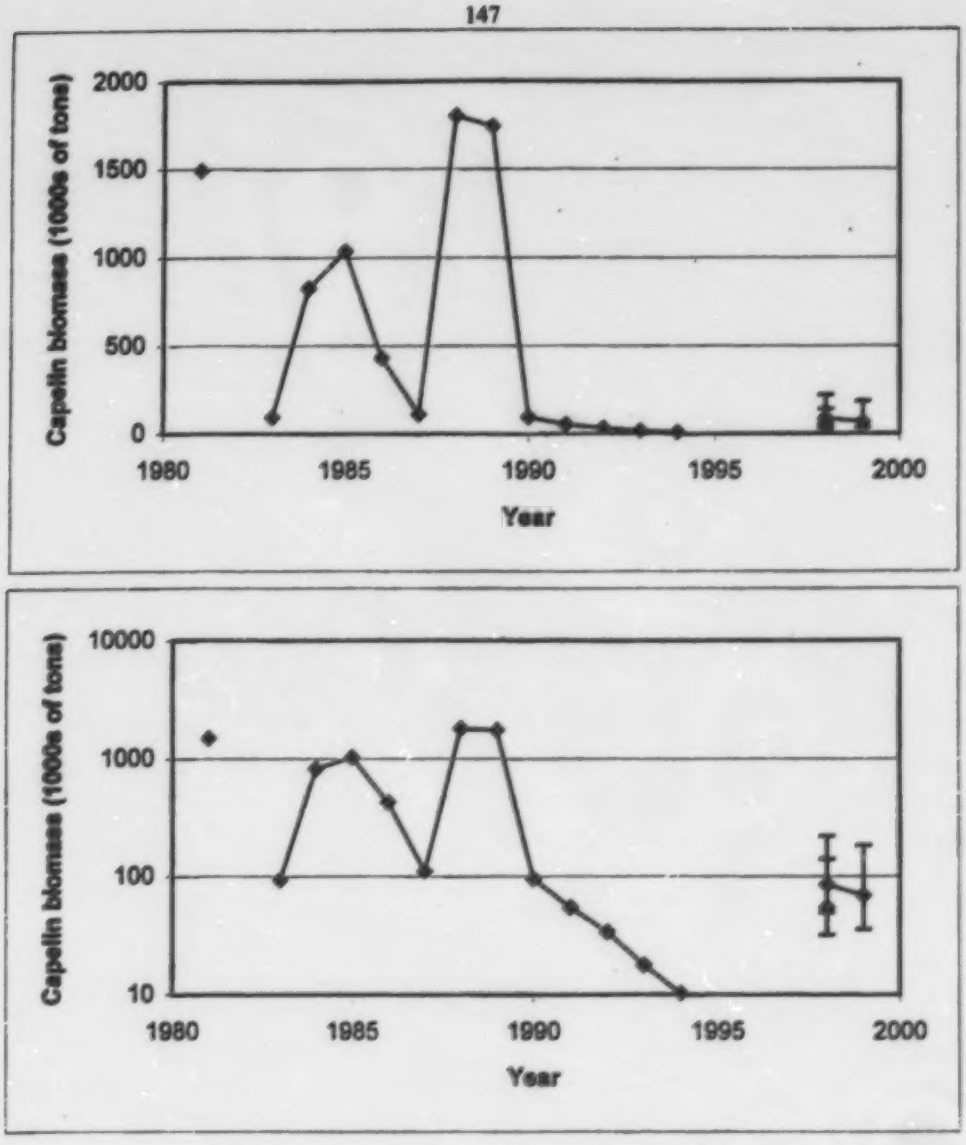

Fig. 6. Comparison of capelin biomass estimates in 2J3K from pelagic juvenile surveys in 1998-1999 (*Method 1*) with estimates from Canadian fall (September-October) acoustic surveys in 1981,1983-1994 (Miller 1995). A capelin target strength of –34 dB kg^{-1} was used in all calculations. In lower figure biomass is plotted on a logarithmic scale. Error bars show 95% confidence intervals. Two estimates are given for 1998. Higher estimate includes correction for depth-variable integration threshold (Table 3). Lower estimate is calculated from uncorrected data (Table 4).

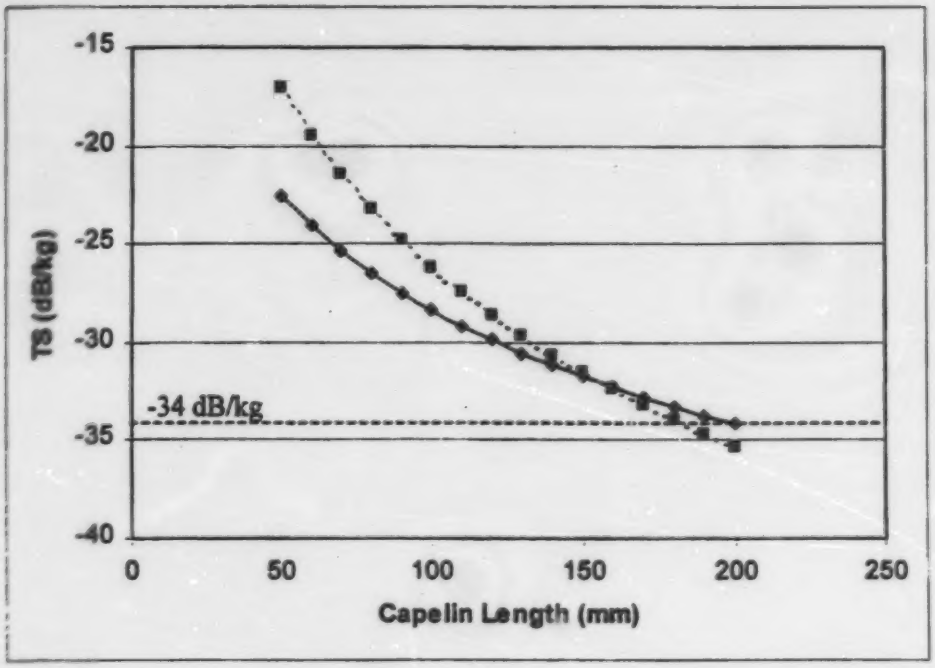

Fig. 7. Relationship between capelin *TS* per unit mass and capelin length based on capelin length-weight relationship from 1999 survey and *TS* models of Rose (1998). Solid line is the length-scaled *TS* model used in *Method 2*. Dotted line is a *TS* model based on both capelin length and weight. See text for details. The capelin *TS* used in *Method 1* is indicated.

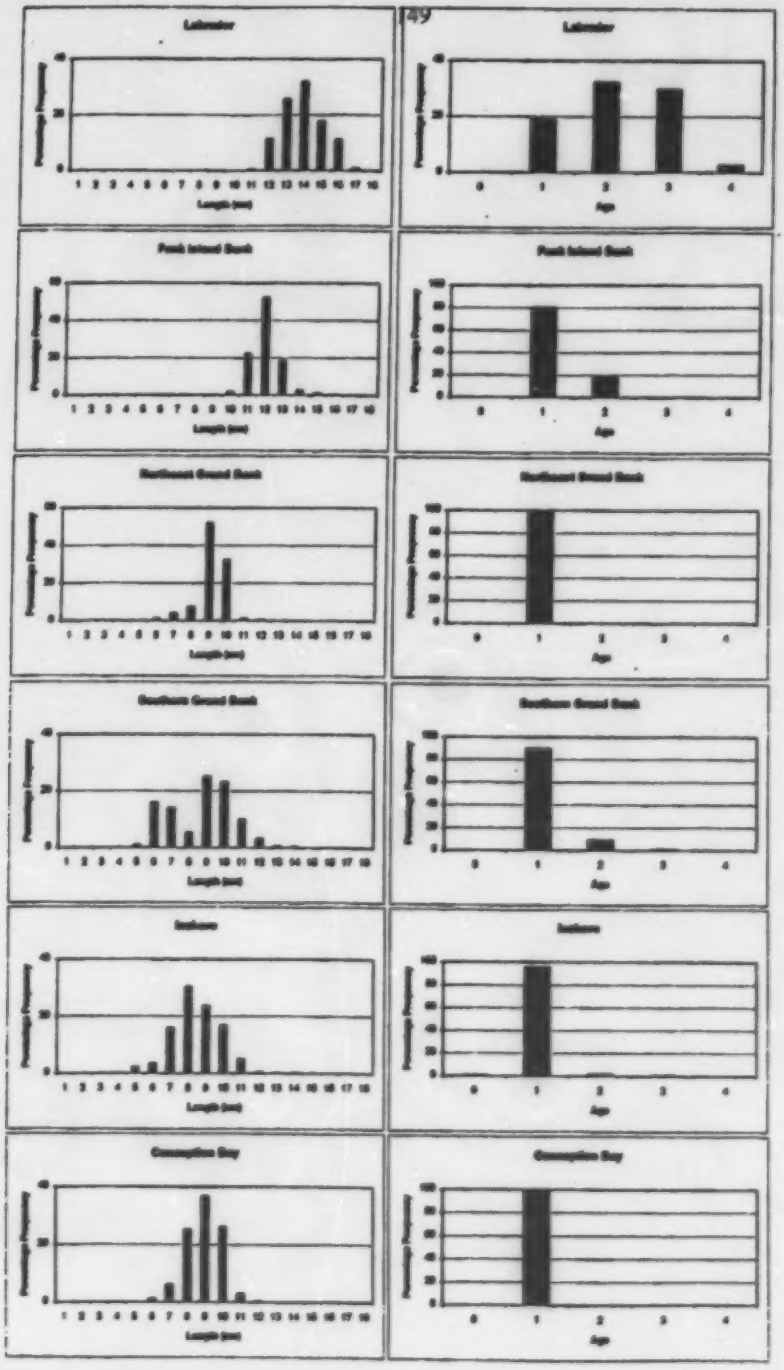

Fig. 8. Length and age composition of capelin caught in representative IYGPT sets in six geographical strata in 1999. See Fig. 4 for strata boundaries. Capelin from Labrador were caught in a targeted trawl at 190 m depth. All other capelin were caught in standard pelagic tows at 20-60 m.

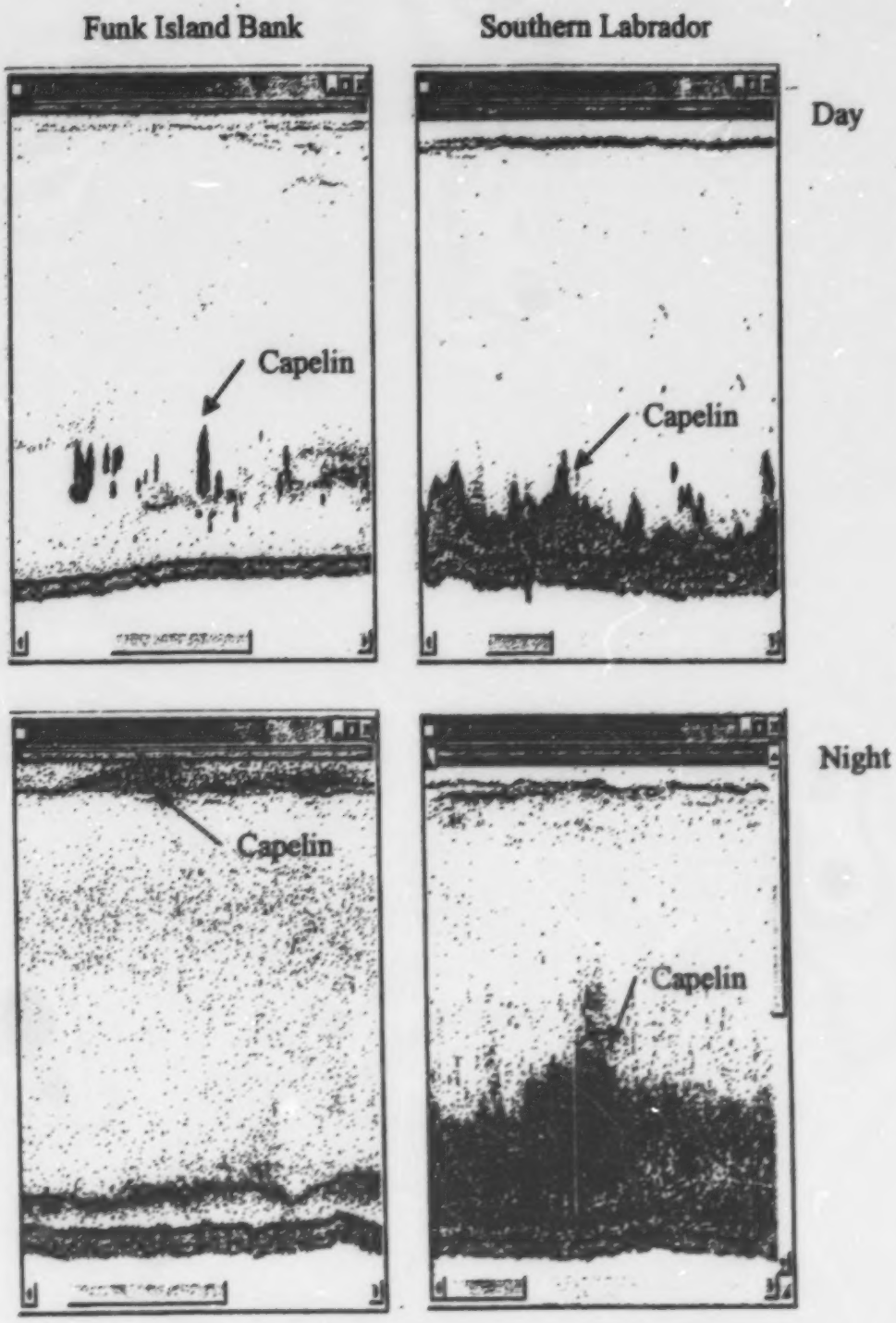

Fig. 9. Echograms showing diurnal variation in vertical distribution of capelin on Funk Island Bank and off southern Labrador. Water depth is ~200 m in each panel. Horizontal scale is ~4 km.

Relationship between acoustic estimates of capelin and trawl catches in Campelen and IYGPT trawls

by

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Abstract

Acoustic estimates of capelin density were compared to catches in Campelen and IYGPT trawls to assess the ability of trawl surveys to index capelin abundance. Trawl surveys were an unreliable indicator of capelin abundance. There were statistically significant, but very weak positive relationships between acoustic estimates of capelin density and trawl catches in the Campelen bottom trawl (n = 148, r^2 = 0.23, $p < 0.001$) and in the IYGPT mid-water trawl towed between 20-60 m depth (n = 82, r^2 = 0.08, p = 0.009). Much of the variability in trawl catches was related to vertical distribution of capelin. Trawl surveys did provide useful information on capelin spatial distribution (presence/absence). There were relatively few sets where capelin were observed acoustically but no capelin were caught. Catchability coefficients calculated for the Campelen and IYGPT trawls were often greater than one, indicating that the trawls caught more capelin than were expected from acoustic measurements of fish density in the trawl zone. Possible explanations for this discrepancy are discussed and the need for further experimental research is emphasised.

Introduction

Capelin are frequently caught in multispecies bottom-trawl surveys (e.g. Lilly 1999) and in mid-water trawl surveys for pelagic juvenile fish (e.g. Anderson *et al.* 1999a) in Newfoundland waters. Interest in the results from trawl surveys has increased since the dramatic decline in abundance of capelin estimated from acoustic surveys in the early 1990s. Annual capelin acoustic surveys were discontinued in 1996 and in recent years survey trawl catches have provided the only fisheries-independent measure of capelin abundance offshore. Capelin catches from fall bottom-trawl surveys in 1985-1994 are currently used in the multiplicative model used to estimate capelin year-class strength (Anon 1999). In 1999 Anderson *et al.* (1999b) used mid-water-trawl catches to estimate absolute abundance of capelin in the Newfoundland region from 1994-1998.

There are two major uncertainties associated with the use of trawl surveys to index capelin abundance. First, both mid-water and bottom trawls target a relatively narrow depth range so there are potential biases in abundance estimates due to the vertical migration behaviour of capelin (e.g. O'Driscoll & Rose 1999). Second, there is uncertainty associated with how effectively the trawl samples capelin in the trawl zone (catchability).

In this paper we present the results of experiments which compared acoustic estimates of capelin abundance with trawl catches in Campelen bottom trawls and IYGPT mid-water trawls. The Campelen trawl is the gear used in multispecies bottom-trawl surveys since 1995 (Lilly 1999). The IYGPT mid-water trawl is towed in an undulating path from 20-60 m depth during the pelagic juvenile survey (Anderson & Dalley 1997). We compared IYGPT catches using this tow pattern with acoustic estimates, and also examined IYGPT catches from targeted (non-undulating) tows on capelin aggregations.

Our work follows on from a previous series of experiments by Miller (1996). This previous study (Miller 1996) was limited because acoustic observations and trawl catches were separated in time and the range of experimental fish densities was narrow. Our study has much larger sample sizes over a broader range of capelin

densities and acoustic measurements were made directly during the fishing sets.

Methods

Experiments using the Campelen bottom trawl were conducted during regular acoustic surveys for cod and capelin during January, March and June 1998, January and June 1999, and January 2000. A total of 149 Campelen sets were examined (Table 1). Sets covered an extensive geographical area, but were concentrated in Placentia Bay (NAFO 3Ps), Trinity Bay (3L), and southern Labrador (2J) (Fig. 1). Ten targeted fishing sets were also made using the IYGPT mid-water trawl during these surveys (Table 1). Most experiments with the IYGPT trawl were conducted during the pelagic juvenile survey in August-September 1999 (Table 1). In these 83 sets the mid-water trawl was towed in an undulating path from 20-60 m following standard pelagic juvenile survey protocol (Anderson & Dalley 1997).

All experiments were conducted from "CCGS Teleost" using trawls fitted to standard specifications. Acoustic data were collected using a calibrated Simrad EK500 split-beam 38-kHz echo-sounder with a hull-mounted transducer, and analysed using custom FASIT and CH2 software. We distinguished signals from capelin based on signal characteristics and information from fishing sets.

Trawls were typically of 15 min (Campelen bottom trawl) or 30 min duration (IYGPT mid-water trawl). Acoustic measurements were made during the fishing sets. To ensure complete spatial and temporal correspondence between acoustic and trawl estimates of capelin density the acoustic file was marked at the start and end of each fishing set. Trawl catches were compared with the acoustic measurements corresponding to the position and duration of the tow with corrections for the distance of the trawl behind the vessel (and hence the hull-mounted acoustic transducer).

We made two comparisons between trawl and acoustic estimates. First, we compared trawl catches with total acoustic estimates of capelin throughout the water column to determine whether trawl catches reflect total capelin abundance. We integrated acoustic data corresponding to the fishing set from 11 m below the surface to the bottom using an integration threshold of -80 dB and scaled by acoustic

target strength to give an acoustic estimate of areal density of capelin (fish m^{-2}) during the set. Capelin target strengths were calculated independently for each set from the length-frequency of capelin in the catch using the relationship $TS = 20\log L - 73.1$ where L = fish length in centimetres (Rose 1998). A corresponding trawl estimate of capelin density (fish m^{-2}) was obtained by dividing the trawl catch (number of fish) by the swept area. Swept area was estimated as the tow length (m) multiplied by the wing spread (17.0 m for Campelen trawl and 9.4 m for IYGPT trawl). We used the comparison of acoustic and trawlable estimates of density to assess detectability of capelin by the trawl.

Second, we compared trawl catches with acoustic estimates of capelin abundance in the trawl zone to examine trawl catchability. For sets with the Campelen bottom trawl the trawl zone was considered to be the area within 5 m of the bottom. The trawl height is only 4.1 m, but allowance was made for the height of the rockhopper rollers and some bouncing of the gear. For targeted IYGPT sets the trawl zone was taken as a zone of 20 m depth around the mean depth of the tow. For undulating pelagic juvenile IYGPT sets the trawl zone was 20-60 m depth. We calculated mean volume scattering (in $m^2 m^{-3}$, equivalent to mean volume backscattering * 4π) from acoustic data in the trawl zone and scaled by set specific acoustic target strength (see above) to give an acoustic estimate of volumetric density of capelin (fish m^{-3}) in the trawl zone during the set. From estimates of volumetric density and volume sampled by the trawl we were able to calculate the "predicted catch" (number of fish) in the trawl based on the acoustic estimate. For the Campelen trawl the volume sampled was calculated based on standard trawl opening (tow length (m) * trawl opening = 69.7 m^2). For IYGPT tows the volume sampled was calculated from actual trawl geometry during the set measured using Scanmar. Note that tow length and sampled volume were based on fishing time only and did not include the period of net deployment and retrieval. Predicted catches were compared to actual catches. We defined the catchability coefficient as the ratio of the actual catch to the acoustically predicted catch.

In summary five measures were calculated for each set:

- Acoustic density (d_A):

$$d_A = \frac{S_A}{\sigma} \qquad (1)$$

where S_A is acoustic area scattering integrated over the whole water column from 11 m to the bottom and σ is the average acoustic cross-section. σ is related to target strength (TS) by the equation:

$$TS = 10\log_{10}(\frac{\sigma}{4\pi}) \qquad (2)$$

- Trawlable density (d_T):

$$d_T = \frac{c_T}{A_T} \qquad (3)$$

where c_T is the catch in the trawl and A_T is the swept area of the trawl calculated from the tow length (l) and the wingspread (w).

$$A_T = lw \qquad (4)$$

- Predicted catch from acoustics (c_A):

$$c_A = \frac{S_V}{\sigma} V_T \qquad (5)$$

where S_V is the mean acoustic volume scattering in the trawl zone. V_T is the volume sampled by the trawl, equivalent to the tow length multiplied by the area of the trawl mouth opening (m).

$$V_T = lm \qquad (6)$$

- Actual catch is the observed catch from the trawl (c_T).

- Catchability coefficient (q):

$$q = \frac{c_A}{c_T} \qquad (7)$$

Results

Campelen trawl detectability

Most estimates of trawlable density of capelin were lower than acoustic density estimates (Fig. 2). This was expected because the Campelen trawl only samples the near-bottom zone (~5 m above the bottom), while acoustic estimates of density are based on samples from almost the whole water column (11 m to the bottom). There were 32 tows when capelin were caught in the trawl but no capelin were measured acoustically. Catches of capelin in these 32 tows were very small (median catch = 6, maximum catch = 111). There were 10 tows when capelin were observed acoustically in the water column, but no capelin were caught in the trawl. There was one anomalously large catch (845 kg) made in Trinity Bay in June 1999 (Fig. 2) which was removed prior to the regression analysis.

Campelen trawl catches were not a good measure of capelin abundance. There was a statistically significant positive regression between acoustic and trawlable estimates of capelin density (Fig. 2), but variability was high (n = 148, r^2 = 0.23, $p < 0.001$). At the same acoustic density, Campelen trawl catches varied by as much as three orders of magnitude (Fig. 2).

Some of the variation in trawlable density was related to the vertical distribution of capelin. We compared acoustic density in the bottom 5 m "trawl zone" with acoustic density in the whole water column. Vertical distribution of capelin showed a diurnal pattern (Fig. 3a), with the majority of sets with capelin concentrated close to the bottom occurring during daylight hours. Most high catches of capelin were also made during the day. Consequently the relationship between trawlable density and acoustic density was stronger during the day (n = 83, r^2 = 0.28, p = 0.003) than at night (n = 66, r^2 = 0.04, p = 0.09) (Fig. 4).

Campelen trawl catchability

Catches in the Campelen trawl were generally similar to predicted catches based on acoustic measurements of capelin density in the trawl zone (Fig. 5). There were 50 tows where low numbers (median catch = 7, maximum catch = 201) of capelin were caught but no capelin were measured acoustically in the trawl zone. There were no instances where capelin were observed acoustically in the trawl zone and not caught. Campelen trawl catchability varied with capelin density (Fig. 6). At low capelin densities (expected catch < 1000), catchability was usually greater than one (n = 26, median q = 5.37), that is the trawl caught more capelin than predicted by acoustic measurements. At high capelin densities (expected catch > 1000) the trawl caught fewer capelin than were observed acoustically and catchability was less than one (n = 16, median q = 0.28).

Undulating (pelagic juvenile survey) IYGPT trawl detectability

Estimates of trawlable density from the IYGPT trawl towed between 20-60 m below the surface are compared with acoustic estimates of density (11 m to the bottom) in Figure 7. No high densities of capelin were detected at trawl stations during the pelagic juvenile survey in 1999, so the range of acoustic densities is less than for the Campelen trawl (Fig. 2). As for the Campelen trawl, there were a number of tows when a few capelin were caught in the trawl but not recorded acoustically (n = 33, median catch = 8, maximum catch = 175). There were 7 sets when capelin were observed acoustically, but no capelin were caught in the IYGPT trawl.

Pelagic juvenile survey IYGPT trawl catches were also a poor indicator of capelin abundance. The relationship between acoustic and trawlable estimates of capelin density was weak and variable (Fig. 7). There was one very large catch of capelin (150 kg) in Conception Bay (Fig. 7). When this outlier was removed, the r^2 for the linear regression was only 0.08 (n = 82, p = 0.009).

Again, some of the variability in trawlable density was related to vertical distribution of capelin. The proportion of capelin in the trawl zone was higher at night (Fig. 3b) and this was when most high catches of capelin

were made. There was a stronger relationship between trawlable density and acoustic density at night (n = 37, r^2 = 0.19, p = 0.006) than during the day (n = 45, r^2 = 0.10, p = 0.03) (Fig. 8).

Undulating IYGPT trawl catchability

Catches in the undulating IYGPT trawl were usually higher than catches predicted by acoustic measurements of capelin in the trawl zone (Fig. 9). There were 40 tows where capelin were caught in the trawl but none were recognised acoustically in the 20-60 m trawl zone (median catch = 6 capelin, maximum catch = 175). There was only one tow where capelin were observed acoustically from 20-60 m but none were caught. Catchability coefficients from the 18 sets where capelin were recorded acoustically and captured were high (median q = 4.43). More capelin were caught in the trawl than predicted by acoustics in 14 of the 18 sets. There was no evidence of a decrease in catchability with increasing capelin density as was observed for the Campelen trawl (Fig. 10), although it should be noted that there was only one set with an expected catch of > 1000 capelin.

Targeted IYGPT trawl detectability

Because these ten sets were targeted on acoustically detected concentrations of capelin we didn't examine the relationship between acoustic density in the whole water column and trawlable density.

Targeted IYGPT trawl catchability

Catches in targeted IYGPT sets were usually lower than predicted catches based on acoustic estimates of capelin in the trawl zone (Fig. 11). In 7 of 10 tows the trawl caught fewer capelin than expected from acoustics. Catchability coefficients ranged from 0.03-11.26 (median q = 0.41).

Discussion

There was little agreement between trawl and acoustic estimates of capelin density for either the Campelen bottom trawl or the IYGPT mid-water trawl. As expected, acoustic density estimates were usually higher than trawlable density estimates because trawls sampled a very limited portion of the water column covered acoustically. Relationships between acoustic and trawl estimates were highly variable. Part of this variability was related to diurnal movement of fish into and out of the trawl zone.

Campelen bottom-trawl catches were generally higher during the day and pelagic juvenile IYGPT catches were almost always greater at night. However, much of the variability in the proportion of capelin in the trawl zone could not be explained by simple day-night differences. The vertical migratory behaviour of capelin appears to be complex, with seasonal (O'Driscoll & Rose 1999) and spatial (O'Driscoll *et al.* 2000) differences in behaviour. Because of these uncertainties associated with vertical distribution and unresolved questions about catchability (discussed below) we believe trawl surveys provide an unreliable estimate of capelin abundance.

Trawl surveys may provide more useful information about capelin distribution (presence/absence). There were relatively few sets where capelin were observed acoustically in the water column but no capelin were caught for either the Campelen (only 10 of 149 sets) or the IYGPT mid-water trawl (7 of 82 sets). The ability of the trawls to sample capelin even when the major concentration was outside the trawl zone was probably related to non-cohesive shoaling behaviour of the fish. There are likely to be a few scattered individuals around a shoal that will be exposed to and sampled by the trawl. Trawls, particularly the Campelen bottom trawl may also have sampled capelin while being deployed or retrieved through the water column.

Trawl sampling may, in fact, be more sensitive to detecting the presence of capelin than acoustic measurements. There were 32 Campelen sets and 33 IYGPT sets where a few (<200) capelin were captured but no capelin were recorded acoustically in the water column. Our inability to measure capelin acoustically at these very low densities is not due to instrumentation. Calculations based on the sampled acoustic volume showed that even individual small capelin would be detected and included in the integration at a threshold of -80 dB. The issue is thus not one of detection, but rather of recognition. Because capelin signal was classified based mainly on signal characteristics, there was potential for an operator to fail to recognise low densities of capelin amongst the other sources of biological scattering.

This "recognition threshold" also accounts for the relatively high number of Campelen (50 of 149) and pelagic juvenile survey IYGPT (40 of 82) sets where capelin were caught but not detected in the trawl zone. In all cases

the number of capelin captured was low. We confirmed that this an issue of recognition and not of detection by integrating total (unclassified) acoustic scattering from the trawl zone. In all cases the amount of total acoustic scattering exceeded the amount which would be caused by these very low densities of capelin. It should be noted that it is not sensible to classify this background level of acoustic scattering as being due mainly to capelin. There are many other biological organisms that contribute to acoustic scattering. Often total scattering from the sample zones of trawls that didn't catch capelin was very much higher than total scattering from trawls with capelin.

Failure to recognise low densities of capelin will tend to bias acoustic estimates downward. However, because the densities involved are very low this bias is probably small. O'Driscoll *et al.* (2000) estimated that ~11,400 tons of capelin was not measured acoustically during the 1999 pelagic juvenile survey due to the recognition threshold. This was 26% of the total survey biomass and well within the range of the sampling uncertainty.

Of greater concern was our observation that at moderate acoustic densities of capelin, both the Campelen bottom trawl and the undulating IYGPT trawl usually caught more capelin than were measured acoustically in the trawl zone ($q > 1$). This was not related to signal classification (recognition of capelin). Even if the total (unclassified) acoustic scattering was all capelin, many of the catches were still greater than expected.

The high levels of catchability we measured for the pelagic juvenile survey IYGPT trawls accounts for the large discrepancy between acoustic and trawl estimates of capelin abundance from the same surveys. Anderson *et al.* (1999b) applied a published (Koslow *et al.* 1997) estimate of catchability of $q = 0.14$ to IYGPT trawl data. Our direct estimate of median catchability for the undulating IYGPT trawl from comparison of trawl catches with acoustic estimates of capelin in the trawl zone was 4.43. The difference between these catchability values would result in a ~30-fold difference in biomass estimates.

Several possible explanations exist for the high catchability we observed. These explanations may be broadly grouped into two categories: 1) trawl catches too high; or 2) acoustic estimates too low.

Trawl catches too high

Estimates of predicted catch were based on the volume filtered during the fishing time of the trawl only and did not include the volume sampled during period of net deployment and retrieval. Scanmar measurements show both trawls appear to have some (reduced) mouth opening during deployment and retrieval so it is likely that capelin are captured during these times. However, the volumes sampled are small relative to the volume sampled during the fishing time. Increasing the sampled volume to include the periods of net deployment and retrieval would not account for the very high catchabilities (median q = 4-5) observed in the undulating IYGPT trawl or the Campelen trawl (at moderate capelin densities) unless capelin densities in the water sampled outside the trawl zone were very much higher than acoustic densities in the zone. We have little acoustic information on capelin densities above the zone of the undulating IYGPT trawl (< 20 m) because of the surface dead-zone (see below). There were sets with the Campelen trawl where very high densities of capelin were observed acoustically above the trawl zone and unexpectedly high catches in these sets may be explained by the net fishing on the way up and down.

Trawl catches could also be increased relative to acoustic estimates due to herding. That is fish becoming concentrated in front of the trawl. One possible biological mechanism for herding would be a tendency to school when danger (in this case a trawl) approaches. We have no evidence that herding occurs for capelin, but this would explain the high catchabilities observed. Density-dependent differences in capelin behaviour in response to the trawl might also account for the decrease in catchability in the Campelen trawl with increasing capelin density.

Small "catches" of capelin when none or few were detected acoustically may arise because of backwash from previous tows. Capelin commonly get meshed in the trawl and are washed into the cod-end on subsequent tows, even when the net is cleaned on deck between deployments (our

personal observations). If tows occur close together in time it is difficult to separate fresh capelin from backwash and this introduces a further (albeit small) level of uncertainty in trawl catches.

Acoustic estimates of capelin density in the trawl zone were based on *mean* volume scattering. There was usually considerable variability in capelin density over the tow length (patchiness). Unexpectedly high catches might result from hitting a high density patch with the trawl. On several occasions there was only one small school observed acoustically during the set (and consequently low mean capelin density), but the trawl catch was high suggesting that the entire school was captured. Patchiness helps explain the variability in trawl catches, but does not explain why catches were consistently higher than predicted by acoustic measurements. We assume the trawl is equally likely to miss a patch as to capture it.

Acoustic estimates too low

We have already discussed how acoustics fails to detect low densities of capelin because of the subjective recognition threshold and pointed out that this does not account for the high catchabilities observed at moderate fish densities. Acoustics might also underestimate capelin density (expected catch) because of boat avoidance, surface and bottom acoustic dead-zones, and acoustic shadowing.

Capelin close to the surface may avoid the vessel. This should not affect comparisons with Campelen bottom trawl catches, but acoustics may underestimate capelin densities in the 20-60 m pelagic juvenile IYGPT trawl zone if capelin avoid the vessel (and the hull-mounted transducer) but not the trawl.

Capelin close to the surface (< 15 m depth) or to the bottom (< 0.5 m above bottom depending on depth) could not be detected acoustically. If high capelin densities occur very near the bottom, acoustics will underestimate the amount of capelin susceptible to the Campelen bottom trawl. The surface dead-zone should not affect our estimates of catchability because both gears were fished below the dead-zone (> 20 m). However, as noted previously, high densities of capelin close to the surface might be captured by the trawl during deployment and retrieval.

At very high fish densities S_A is not proportional to fish density because fish nearest the transducer attenuate the echo energy so that it cannot penetrate to the more distant fish (MacLennan & Simmonds 1992). We do not believe this was a major source of bias in our experiments because capelin densities were not very high.

A further source of uncertainty in acoustic estimates is target strength. Expected catch was determined from acoustic estimates using the length-target strength relationship of Rose (1998) and the lengths of capelin caught in each set. If we apply an alternative target strength model to our data ($TS = 19.1\log L - 74.0$; Toresen *et al.* 1998) expected catch is increased by about 1.5 times, but estimates of trawl catchability (q) still usually exceed one for the undulating IYGPT trawl and the Campelen trawl at moderate capelin densities.

Our observations of high catchability support the earlier findings of Miller (1996). Miller (1996) found that trawl catches of capelin in the IYGPT (5 of 12 sets) and Campelen trawls (19 of 19 sets) were often higher than acoustic estimates. These two studies suggest that further experimental work is required to examine capelin behaviour in response to trawling. Understanding of catchability and also capelin vertical distribution patterns are required before trawl surveys can be used to provide estimates of capelin abundance.

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References

Anderson, J.T. and Dalley, E.L. 1997. Spawning and year-class strength of northern cod (*Gadus morhua*) as measured by pelagic juvenile cod surveys, 1991-1994. Can. J. Fish. Aq. Sci. 54(Suppl. 1): 158-167.

Anderson, J.T., Dalley, E.L. and Davis, D.J. 1999a. Year-class strength of northwest Atlantic capelin (2J3KLNO) estimated at the larval stage and age one based on pelagic juvenile fish surveys 1994-1998. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206.

Anderson, J.T., Dalley, E.L. and Carscadden, J.E. 1999b. Absolute abundance and biomass of juvenile and adult capelin (*Mallotus villosus*) in the Newfoundland region (2J3KLNO) estimated from the pelagic juvenile fish surveys, 1994-1998. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206.

Anon. 1999. Capelin in 2J3KL. DFO Stock Status Rep. B2-02.

Koslow, J.A., Kloser, R.J. and Williams, A. 1997. Pelagic biomass and community structure over the mid-continental slope off southeastern Australia based upon acoustic and midwater trawl sampling. Mar. Ecol. Prog. Ser. 146: 21-35.

Lilly, G.R. 1999. By-catches of capelin during spring and autumn bottom-trawl surveys in Divisions 2J3KL in 1998. *In* Capelin in SA2 + Div. 3KL CSAS Res. Doc. 99/206.

MacLennan, D.N. and Simmonds, E.J. 1992. Fisheries acoustics. Chapman and Hall, London.

Miller, D.S. 1996. Observations on the relationship between acoustic estimates and trawl catches. DFO Atl. Fish. Res. Doc. 96/90 pp 176-184.

O'Driscoll, R.L. and Rose, G.A. 1999. Seasonal changes in abundance, distribution and vertical migration of capelin in Placentia Bay. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206 pp???

O'Driscoll, R.L., Anderson, J.T. and Mowbray, F.K. 2000. Abundance and distribution of capelin from an acoustic survey in conjunction with the 1999 pelagic juvenile

survey. *In* Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 2001/161.

Rose, G.A. 1998. Acoustic target strength of capelin in Newfoundland waters. ICES J. Mar. Sci. 55: 918-923.

Toresen, R., Gjosaeter, H. and de Barros, P. 1998. The acoustic method as used in the abundance estimation of capelin (*Mallotus villosus* Muller) and herring (*Clupea harengus* Linne) in the Barents Sea. Fish. Res. 34: 27-37.

Table 1. Summary of experimental sets used to compare acoustic estimates and trawl catch.

Cruise	Survey Date	Survey Areas	Number of Experimental Sets		
			Campelen	Undulating IYGPT	Targeted IYGPT
Teleost 59	1-17 Jan 98	2J,3Ps	7		
Teleost 60	28 Mar-2 Apr 98	3Ps	13		
Teleost 65	7-26 Jun 1998	2J,3L,3Ps	53		4
Teleost 77	4-16 Jan 1999	2J,3K,3L,3Ps	26		3
Teleost 79	30 May-18 Jun 99	2J,3L,3Ps	34		2
Teleost 81	23 Aug-17 Sep 99	2J,3K,3L		83	1
Teleost 89	4-16 Jan 2000	2J,3K,3L	16		

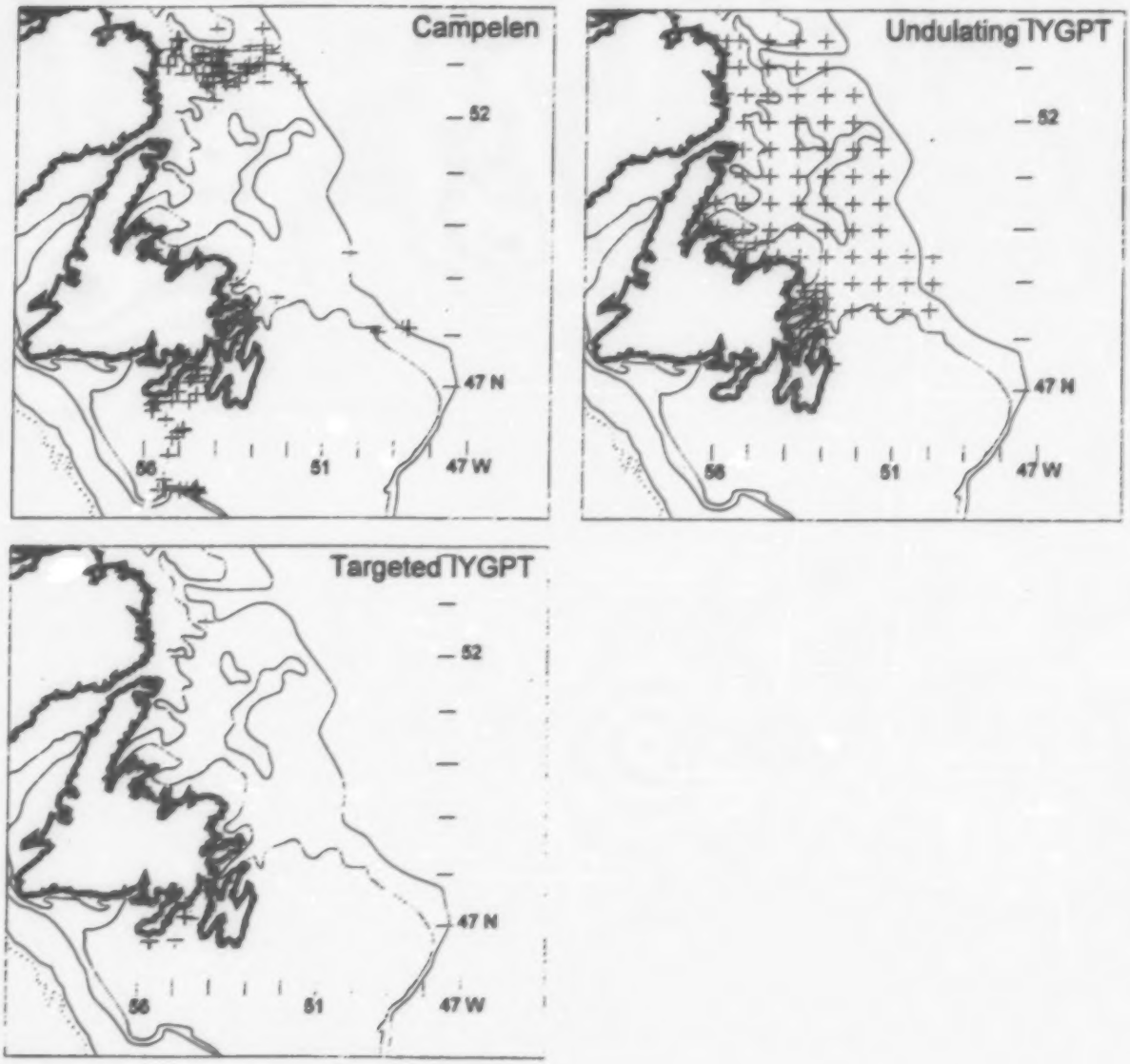

Fig. 1. Location of experimental sets used to compare acoustic estimates and trawl catch.

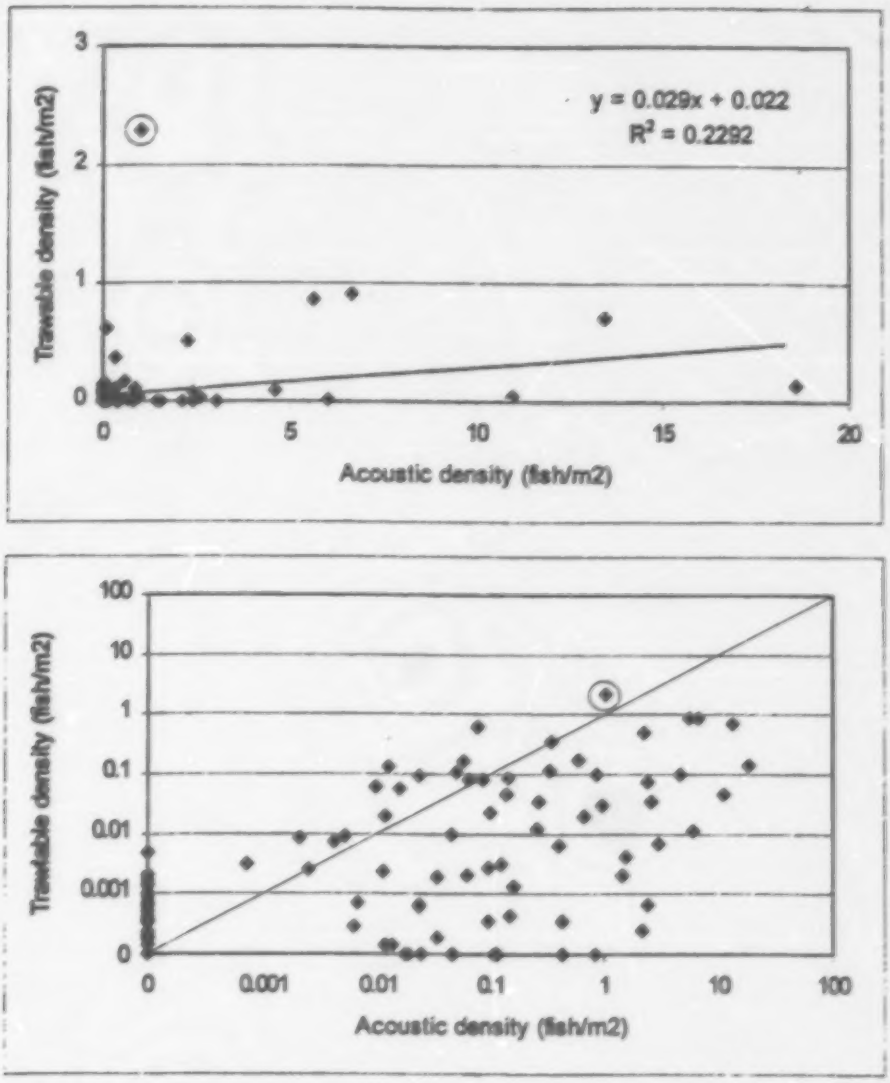

Fig. 2. Comparison of trawlable capelin density calculated from Campelen trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom). Circled point was removed prior to regression analysis. Lower plot is the same data on a log scale with a line indicating x = y.

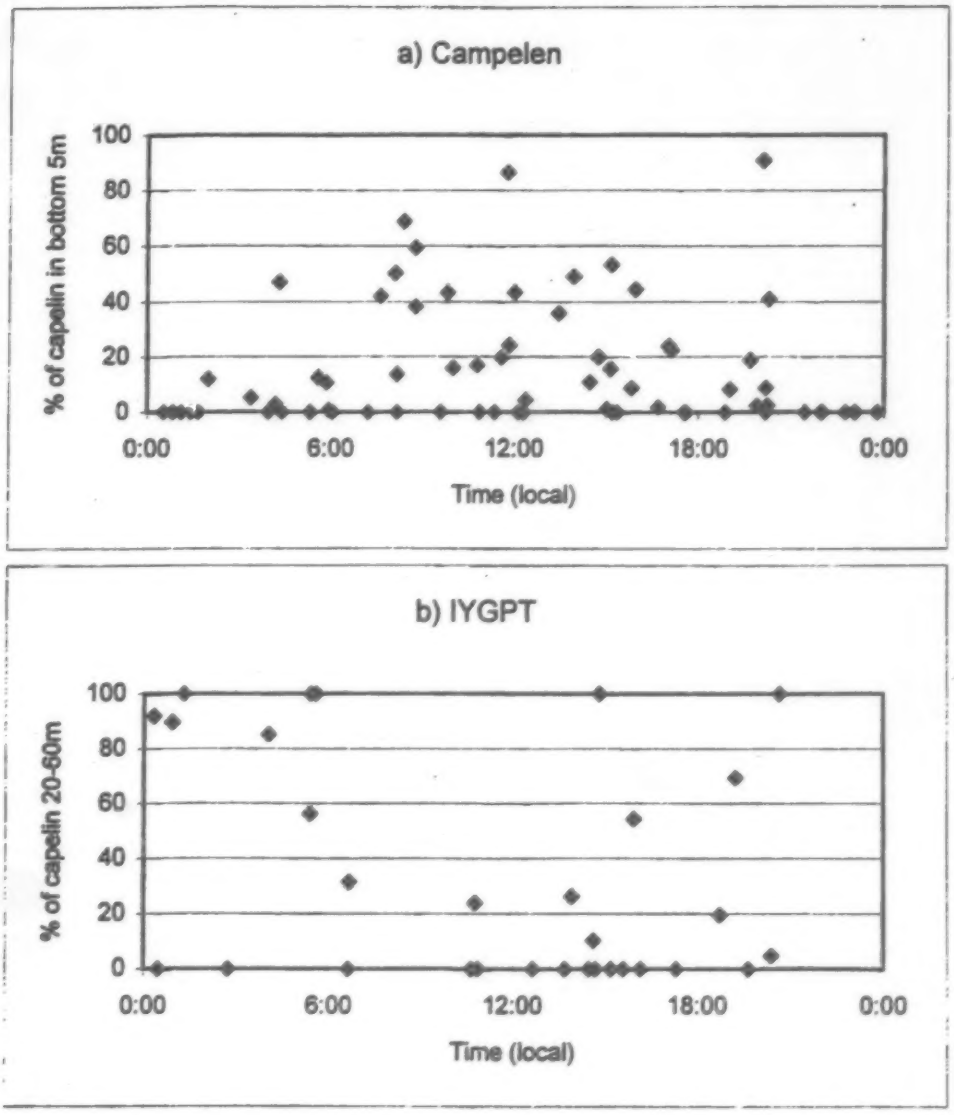

Fig. 3. Diurnal differences in the proportion of capelin detected acoustically in the trawl zone for experimental sets with a) Campelen (trawl zone 5 m from bottom) and b) undulating IYGPT mid-water trawls (trawl zone 20-60 m depth).

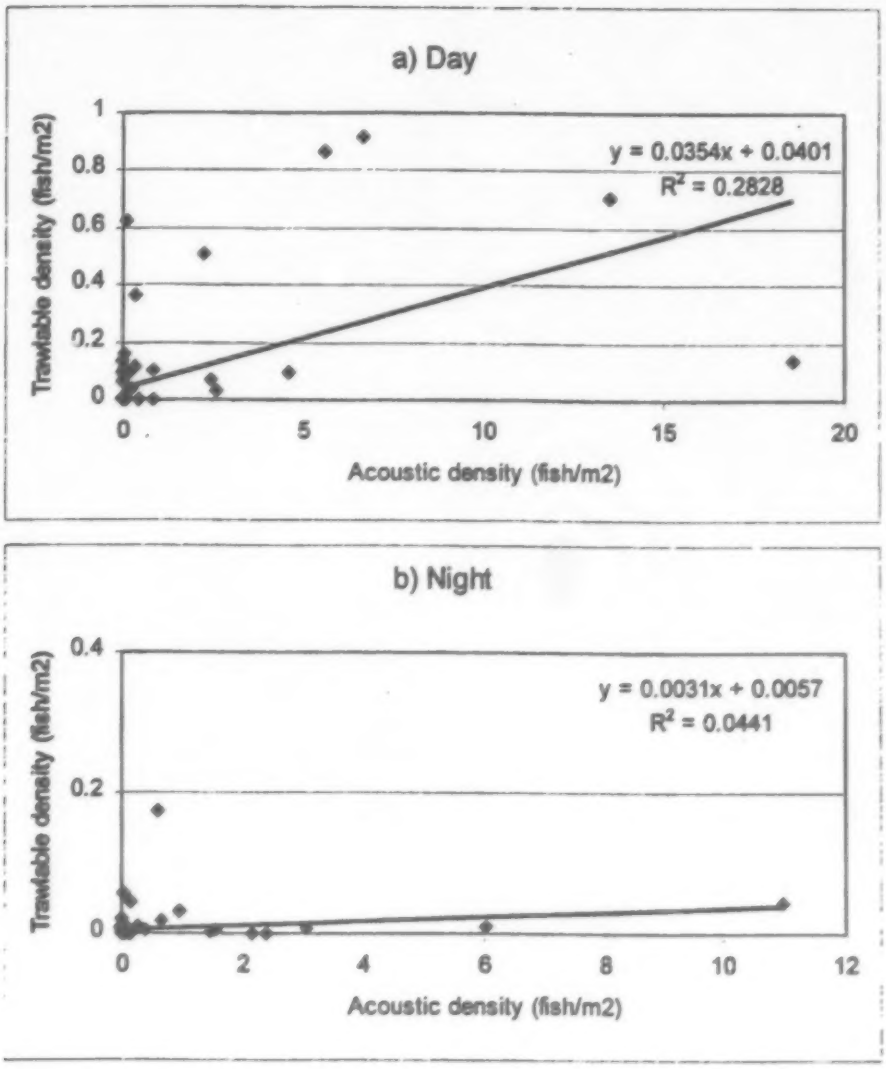

Fig. 4. Comparison of trawlable capelin density from Campelen trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom) for experimental sets during a) daylight and b) at night.

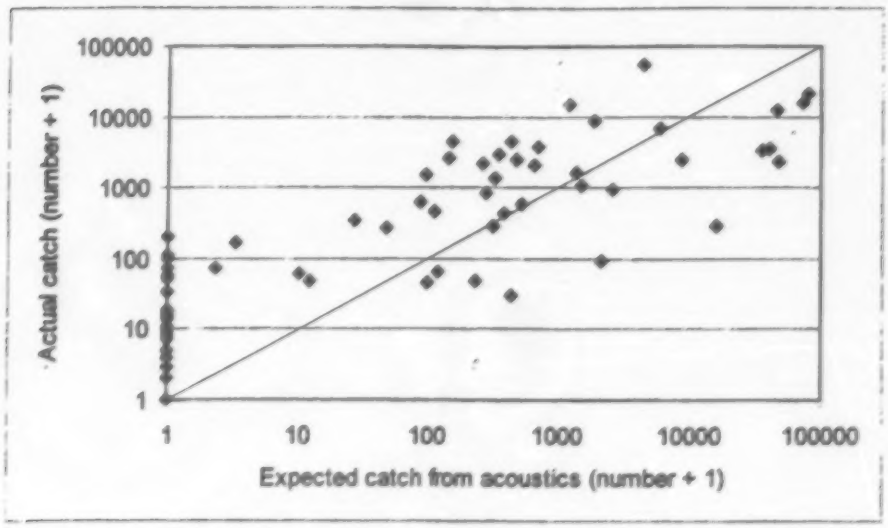

Fig. 5. Comparison of observed and expected catches of capelin in the Campelen trawl. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (5m from bottom). Data are plotted on a log scale. Line indicates a catchability of one.

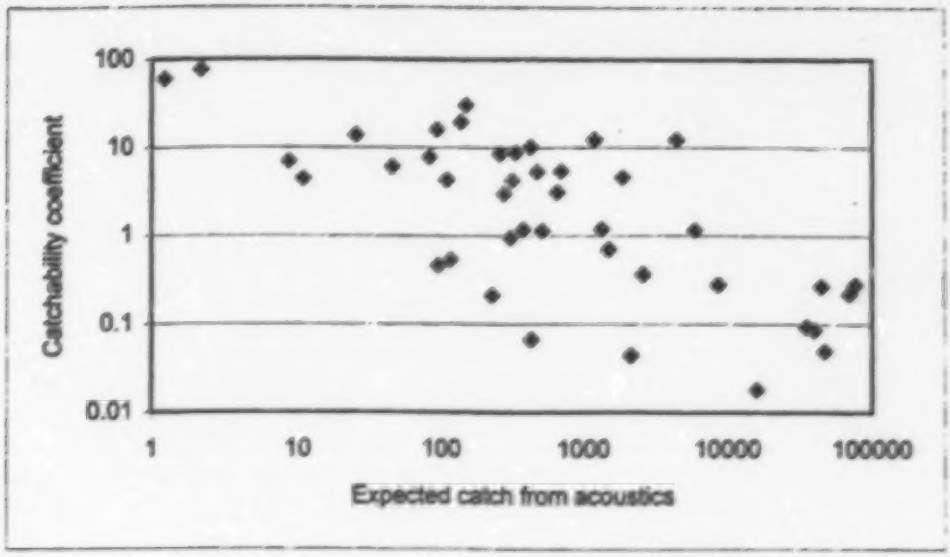

Fig. 6. Catchability in the Campelen trawl as a function of acoustic density of capelin in the trawl zone. Catchability is the ratio of observed to expected catch of capelin. Data are only plotted for sets where capelin were detected acoustically and caught.

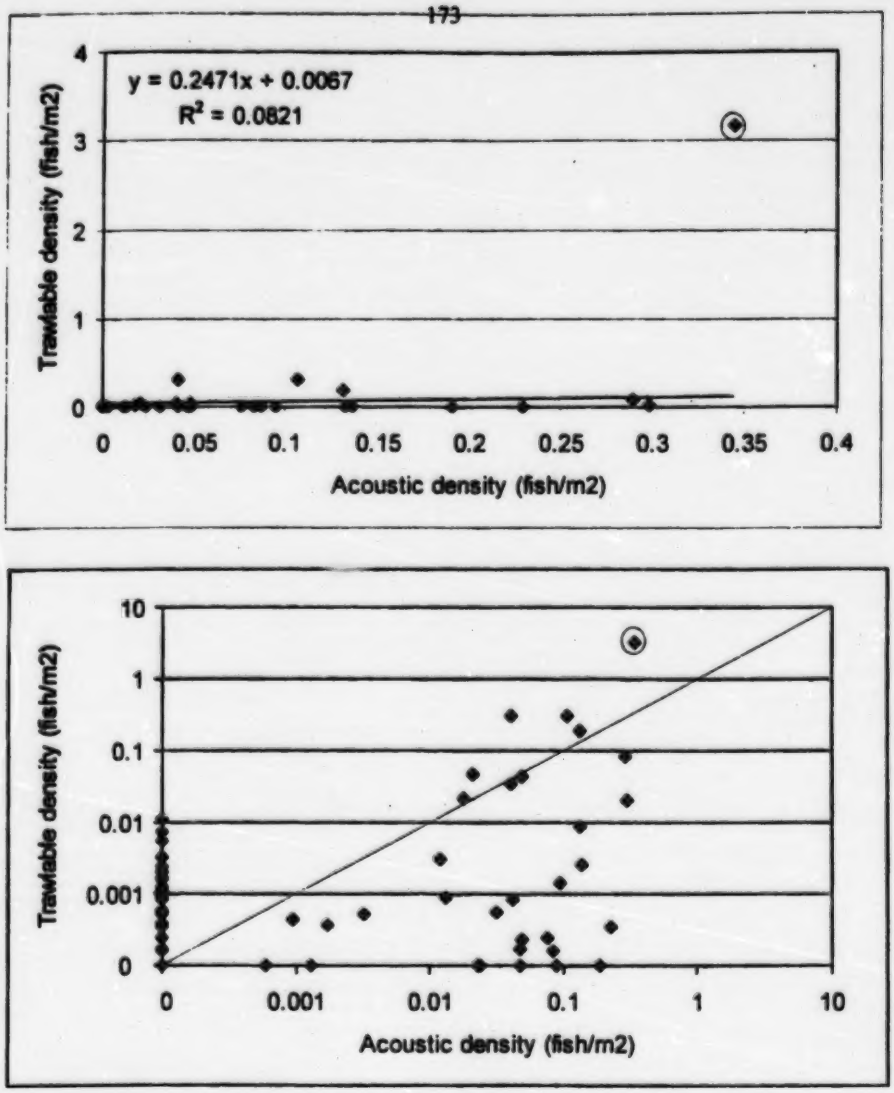

Fig. 7. Comparison of trawlable capelin density calculated from undulating (20-60 m depth) IYGPT trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom). Circled point was removed prior to regression analysis. Lower plot is the same data on a log scale with a line indicating x = y.

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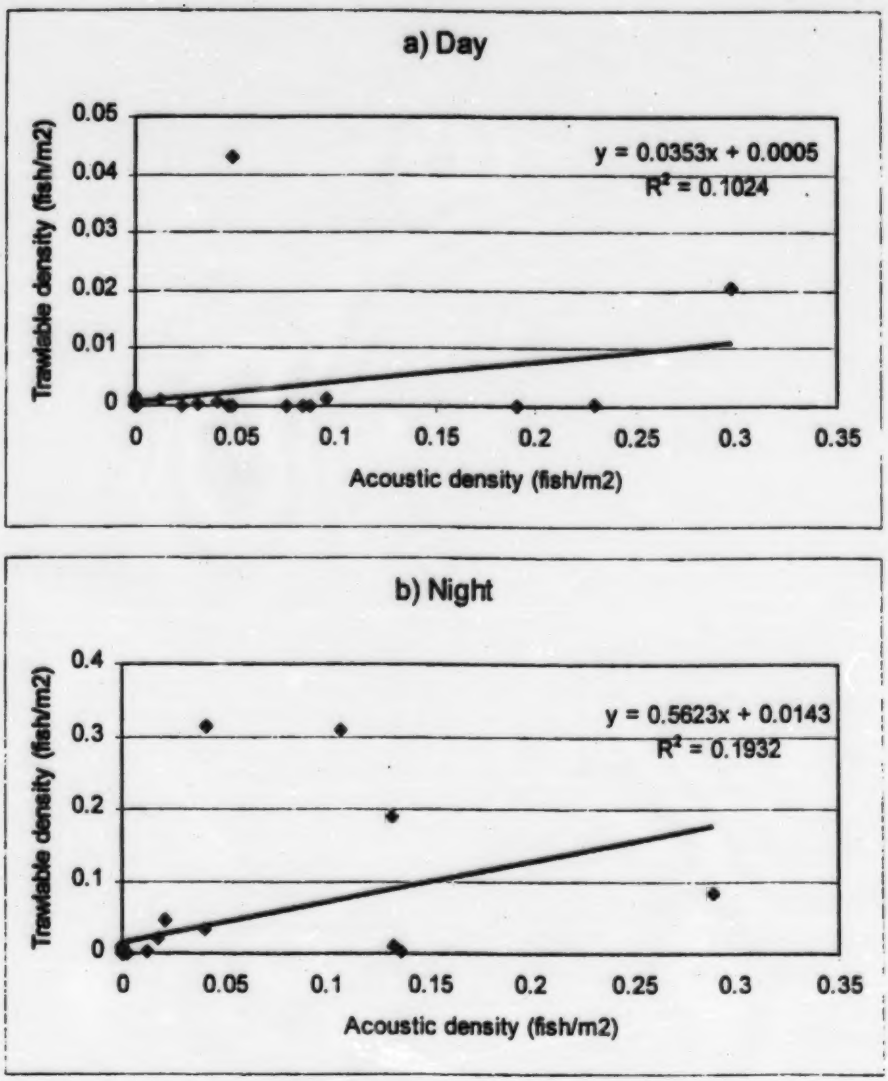

Fig. 8. Comparison of trawlable capelin density from undulating IYGPT trawl catches with acoustic density of capelin throughout the water column (11 m to the bottom) for experimental sets during a) daylight and b) at night.

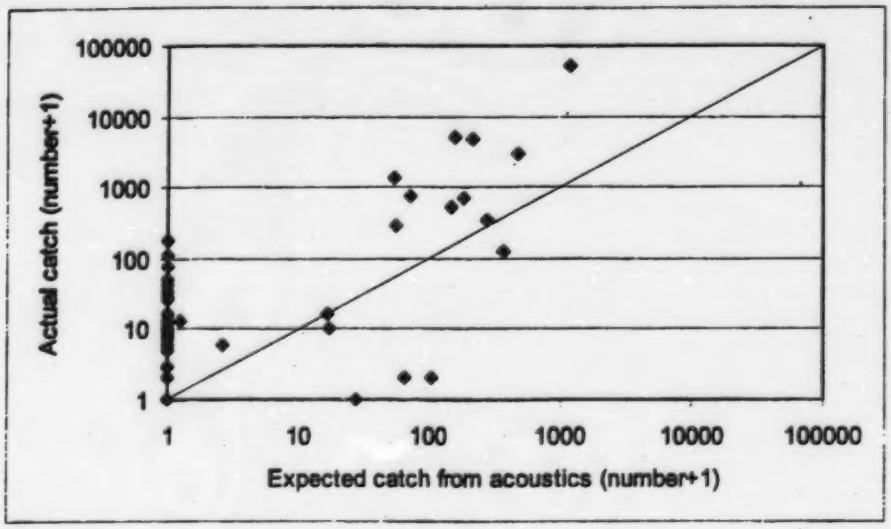

Fig. 9. Comparison of observed and expected catches of capelin in the undulating IYGPT trawl. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (20-60 m depth). Data are plotted on a log scale. Line indicates a catchability of one.

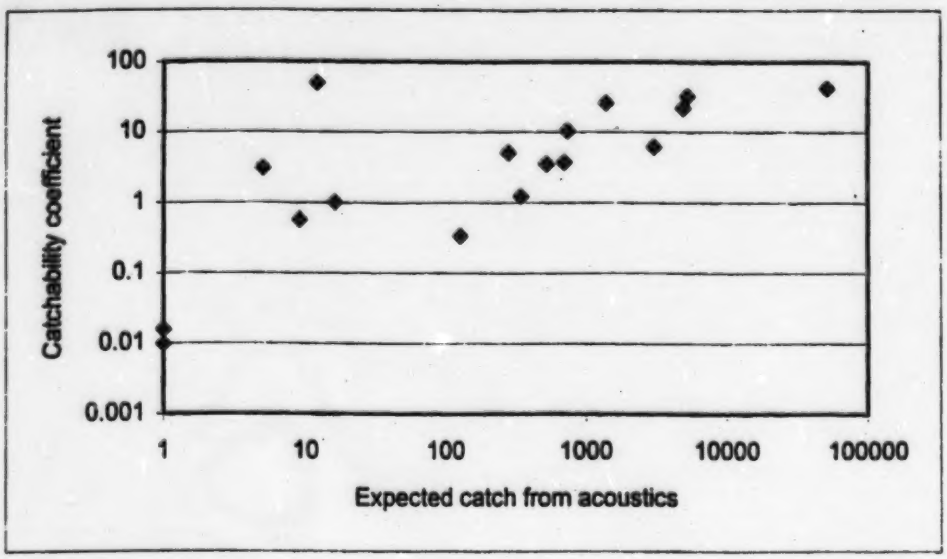

Fig. 10. Catchability in the undulating IYGPT trawl as a function of acoustic density of capelin in the trawl zone. Catchability is the ratio of observed to expected catch of capelin. Data are only plotted for sets where capelin were detected acoustically and caught.

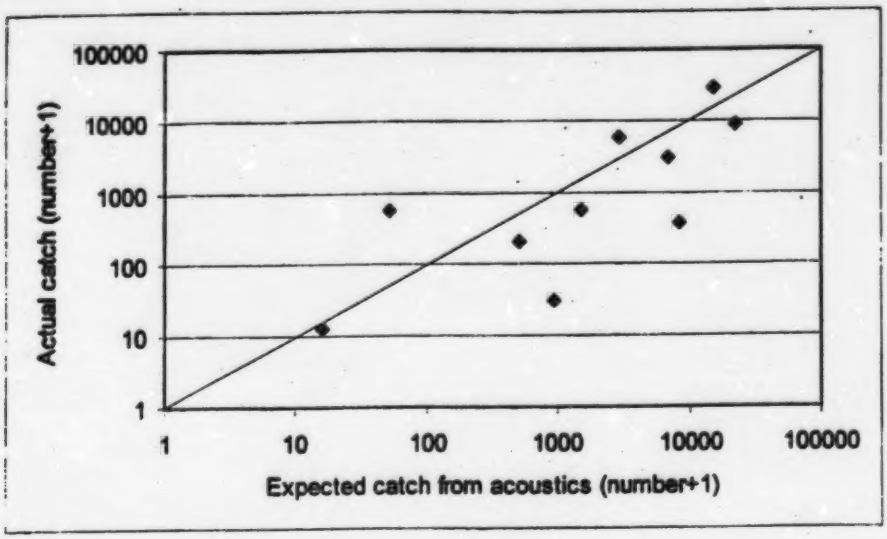

Fig. 11. Comparison of observed and expected catches of capelin in targeted IYGPT trawls. Expected catches were calculated from acoustic estimates of capelin density in the trawl zone (20 m around targeted depth). Data are plotted on a log scale. Line indicates a catchability of one.

Predicting Mean Lengths of Female Capelin in SA2+Div. 3KL

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Introduction

In past assessments, it has been noted that there is a positive relationship between mean lengths of maturing capelin from fall offshore surveys and the mean lengths of spawning capelin the following year. In fact, two relationships might exist, one for the fall/summer mean length combination 1981/1982 to 1989/1990 and from 1990/1991 onward (Carscadden and Evans 1998). These authors also reported that growth between the fall of one year and spring of the following year could not be predicted. As a result, since that assessment, two probability distributions, using data from the 1980s and 1990s, have been produced to provide insight into the likely mean lengths of the females in the mature population the following spawning season (Carscadden et al. 1999).

In this paper, we present the mean lengths of females sampled during 1999, thereby providing an evaluation of the probability distributions presented the previous year (Carscaden et al 1999). In addition, we present another probability distribution analysis using historical mean length data and the observed mean lengths of female capelin during the fall of 1999.

The 1999 Analysis and Prediction

From capelin by-catch in the Campelen gear in the autumn 1998 groundfish survey in Div. 2J3KL, the mean length of maturing females was 139 mm, one of the smallest estimates in the series. Using data from the 1980s and 1990s, probability distributions were presented. If growth increments between the sampling period during the fall of 1998 and spring 1999 resembled growth increments observed in the 1990s, there was no chance that the average counts would be less than 50 (ie. mean length greater than 151 mm). If growth increments were similar to those observed during the 1980s, there was about a 75% chance that the average counts in 1999 would be less than 50.

The mean length of mature female capelin in the 1999 commercial fishery was 150 mm. This mean length falls in the group of mean lengths from the 1990s (Fig 1), suggesting that growth between the fall of 1998 and spring of 19999 was again low and typical of the 1990s.

Predicted Mean Length of Females in 2000

The only source of samples from the autumn in 1999 was by-catch in the Div. 2J3KL groundfish survey using Campelen gear. The overall mean length of maturing female capelin in the fall of 1999 was 144 mm which is 5 mm larger than the mean lengths of maturing females in 1998 and in the mid-range of mean lengths from the 1990s (Table 1).

Using the non-parametric method of Evans and Rice (1988), we present a probability distribution for the mean length of 144 mm measured in the fall of 1999. Two distributions are presented: one if the increments of the 1990s prevail, another (higher) if the system reverts to the increments of the 1980s. For reference, we also illustrate the positions of lengths corresponding to the approximate 50 and 40 counts (Fig. 2). The positions of the 50 and 40 counts are approximate. They are derived from length-weight regressions for females during the spawning season and the weights of these females (from which counts are derived) are variable at this time because of rapid maturation.

If growth between late 1999 and the 2000 fishery is similar to that observed during the 1990s, there is about a 50% probability that counts will average less than 50 (Fig. 2). On the other hand, if growth is similar to that observed during the 1980s, there is a 100% probability that counts will average less than 50 and about a 65% probability that counts will average less than 40.

These graphs (Fig. 2) describe only the variation in increments observed since 1981 and cannot rule out accidents as yet unobserved. The analysis is based on pooled data from the stock area and consequently, it is not possible to account for differences that may occur between geographical areas and between spawning runs.

References

Carscadden, J., and G. T. Evans. 1998. Predicting mean lengths of female capelin in SA2+Div. 3KL. pp. 72-90. In Capelin in SA2+ Div. 3KL. DFO CSAS Res. Doc. 98/63, 152 pp.

Carscadden, J., G. T. Evans, and B. S. Nakashima. 1999. Predicting mean lengths of female capelin in SA2+Div. 3KL. pp. 162-168. DFO CSAS Res. Doc. 99/206, 196 pp.

Evans, G. T., and J. C. Rice. 1998. Predicting recruitment from stock size without the mediation of a functional relation. J. Cons. Int. Explor. Mer. 44: 111-122.

Table 1. Mean lengths of mature females inshore during the spawning season and maturing females during the fall. All inshore mean lengths are derived from fishery data except 1994 and 1995 which are derived from collections from spawning beaches. The lengths are provided for the actual year of collection, however, the relationships illustrated in Figure 1 compare mean lengths in the fall to mean lengths inshore the following year.

Year	Mean lengths inshore (mm)	Mean lengths fall (mm)
1981		137
1982	166	147
1983	163	151
1984	170	146
1985	161	146
1986	165	163
1987	172	160
1988	170	148
1989	167	150
1990	167	159
1991	159	145
1992	151	146
1993	152	143
1994	152	131
1995	142	141
1996	151	149
1997	149	144
1998	147	139
1999	150	144

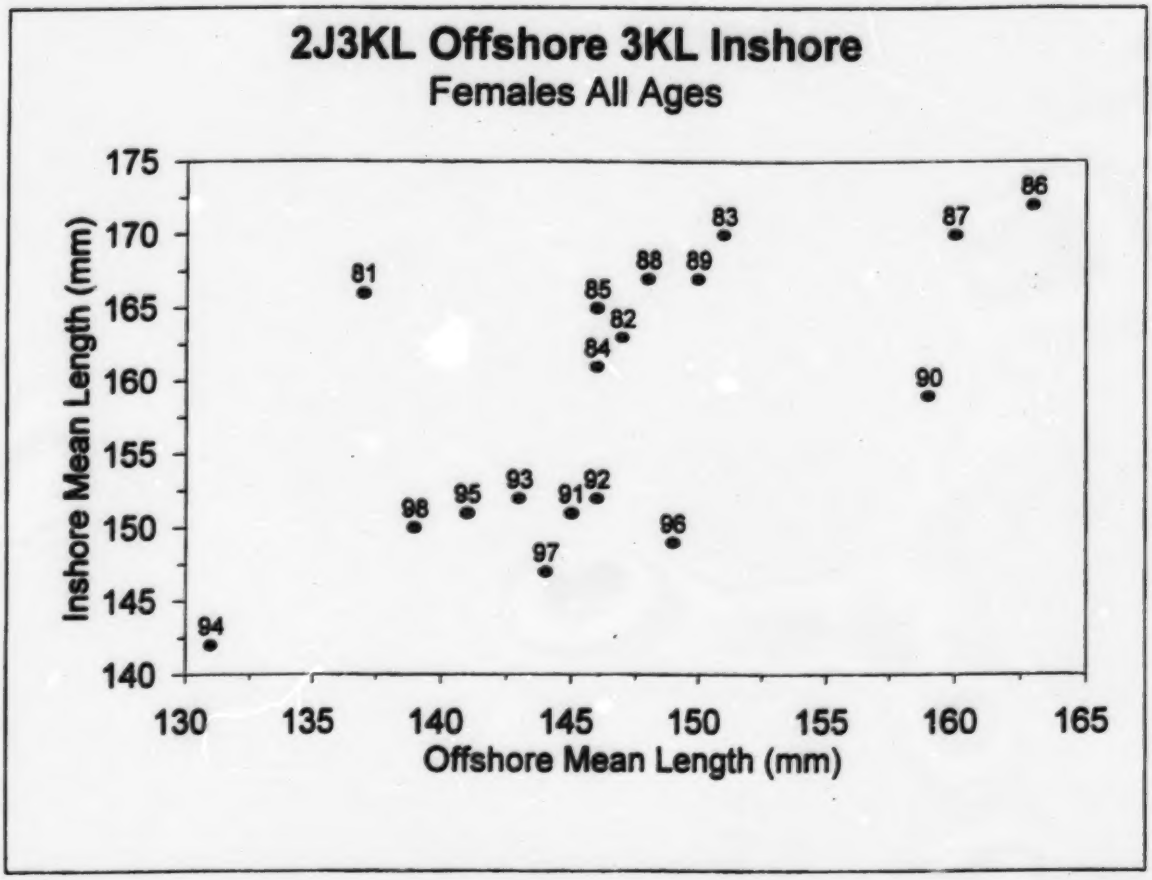

Fig. 1. Relationship between mean lengths of mature female capelin from fall offshore surveys and from inshore the following year, fall 1981 to inshroe 1999. The labels (year) are the year the fall samples were collected (eg. 81 point is for fall 1981/inshore 1982).

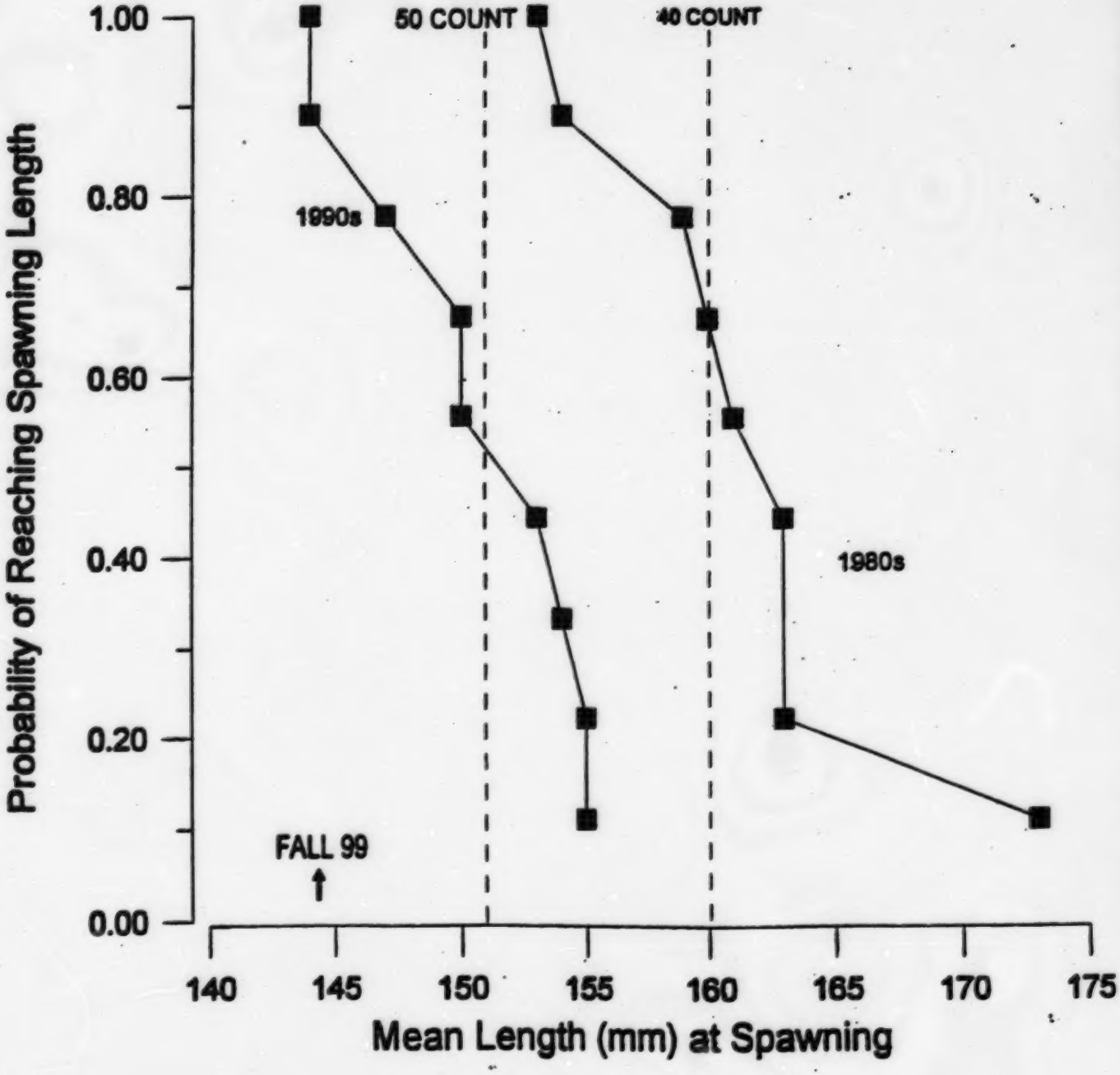

Fig. 2. Probabilities of reaching particular spawning lengths using growth increments observed during the 1980's and 1990's, and a fall mean length of 144 mm. The dotted lines identify the approximate mean lengths corresponding to 50 and 40 count (numbers of females per kg.) capelin.

Trends in Yearclass Strength of Capelin (Mallotus villosus)

by

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Introduction

The multiplicative model provides an objective framework for combining indices from a variety of sources into a single compromise index (see Myers et al. 1993). This approach is particularly attractive for extraction of the yearclass effect because multiple estimates from several abundance indices can be combined over a life-span. The multiplicative approach was applied to capelin for the first time in the 1995 assessment (Anon. 1995) with indices receiving equal weight. For the 1999 assessment, a weighted multiplicative model was employed to estimate a standardized index of cohort strength (Nakashima and Evans 1999).
For the 2000 assessment indices previously excluded, i.e. Canadian acoustic surveys, were included in the evaluation.

Methods

The multiplicative cohort model assumes that the various types of abundance indices to be integrated remain proportional to population abundance (and therefore each other) throughout the time series so that gaps and missing values can be filled in through standardization into a combined index.

The general multiplicative model took the form:

$$N_{ijkt} = I\ C_k\ S_j\ A_i\ \epsilon$$

where I = intercept
C_k = cohort effect
S_j = survey effect for $j = 1 \ldots 13$
A_i = age effect for $i = 0 \ldots 5$
ϵ = residuals from fitted model

and N_{ijkt} = number at age i from survey j belonging to cohort k in year t.

All variables were log-transformed (i.e. multiplicative model becomes an additive model) and the estimated cohort strengths were obtained after exponentiation.

A multiplicative analysis was performed as in Anon. (1995). The variance of each index about the combined estimate was computed. For the group of indices comprising 1/3 of the total that had the smallest variances, their variances were replaced by the largest variance in the group. Thus exceptionally, possibly accidentally small variances were ignored. The multiplicative analysis was then repeated with each index weighted by the reciprocal of its variance.

For the most recent yearclass, a probability distribution for yearclass strength was developed combining the empirical distributions for expected yearclass strength and expected catchability of the few available indices, using Bayes rule (Evans 2000).

To develop a standardized cohort index for the 2000 assessment, a multiplicative model was applied to thirteen indices. Seven indices were chosen as the basis for the 1995 assessment, i.e. catch rates from purse seines and traps, the aerial survey index, egg deposition, the Russian 2J3K CPUE, and Canadian 2J3K and 3L fall bycatch indices from offshore groundfish surveys. Five indices that were the basis of a standardized recruitment index in the 1998 assessment (Nakashima 1998) were combined with the original seven indices for the 1999 assessment (Nakashima and Evans 1999). For this assessment we excluded the Bellevue Beach sediment larval index because of worries that it is not independent of the Bellevue Beach larval index and included two Canadian acoustic surveys because discrepancies would be accounted for in weighting.

Results and Discussion

Indices

The multiplicative model was applied to the following indices to estimate a standardized cohort index for the 2000 assessment of 2J3KL capelin (Appendix A):

1. aerial survey index 1982-98, excluding 1991;
2. egg deposition index 1990-99;
3. purse seine catch rate index 1981-93, 1996;
4. integrated trap catch rate index 1981-93;
5. groundfish 3L fall bycatch 1985-94;
6. groundfish 2J3K fall bycatch 1985-94;
7. Russian 2J3K fall commercial catch rate index 1972-91;
8. Conception Bay sediment larval index 1987, 1989-93;
9. Bellevue Beach emergent larval index 1990-96, 1998-99;
10. Offshore Div. 2J3KLNO 0-group index 1994-99;

11. Offshore Div. 2J3KLNO age 1 index 1994-99.
12. Canadian Div. 3L spring acoustic survey 1982-91, 1996;
13. Canadian Div. 2J3KL fall acoustic survey 1981, 1983-94.

(a) Aerial survey index

No aerial survey was conducted in 1999.

(b) Egg deposition index

Egg deposition (stages I-II, integrated for each beach) has been estimated since 1990 for several beaches on the northeast coast. For the 1999 assessment we used the Bellevue Beach data series (Nakashima and Slaney 2000a). To estimate the number of females we divided egg deposition by the mean female weight in gm. The estimate was then partitioned for the cohort model using the female age composition from biological samples collected at Bellevue Beach (Nakashima and Slaney 2000a). The egg deposition time series was first adopted as an index in the 1996 assessment (Winters 1996) and serves as an indirect measure of female spawner escapement. Retention of the index in the analysis assumes that observations at Bellevue Beach are indicative of an overall trend in beach spawning for Div. 3KL.

(c) Purse seine index

Data were available to estimate a purse seine catch rate (catch per fishing day) for the 1999 mobile fishery. Details concerning the purse seine fishery in 1999 are in Nakashima and Slaney (2000b). The purse seine catch rate for 1999 was not used in the standardized cohort model this year. The low number of returns reflecting the low participation in the fishery and nature of the fishery created difficulties in evaluating the relevance of the recent catch rates to those in the early part of the series.

(d) Integrated trap index

Data were unavailable from the research logbook survey to estimate an integrated trap index for 1999. The monitoring program to determine area openings and marketing constraints have changed fishing practices. Only 20 research logbook fishers participated in the fishery. Most of the data came from White Bay and Trinity Bay and no fishery took place on the Southern Shore or in St. Mary's Bay (Nakashima and Slaney 2000b). No acceptable method was available to make the 1999 estimate compatible with estimates earlier in the time series. Therefore no estimate for 1999 was used in the analysis.

(e) Offshore indices

These include the Russian 2J3K CPUE series and the 2J3K and 3L bycatch (%) of capelin in the fall 2J3KL groundfish survey (see Lilly 1995). The Russian 2J3K CPUE series ended in 1991. The two fall groundfish bycatch indices ended in 1994 when the survey fishing gear was changed from an Engels 145 high-lift trawl to a Campelen 1800 shrimp trawl.

(f) Inshore 0-group indices

The inshore indices were based on very early estimates of 0-group fish. Sediment larvae are newly hatched capelin larvae resident in beach sediments for 1-5 days. When larvae are released from beach sediments into the water column they are then termed emergent larvae. Sediment larvae were estimated from 15 Conception Bay beaches in 1987 and 1989-93 (Winters et al. 1996). Emergent larvae were enumerated at several northeast coast beaches including Bellevue Beach since 1990. The Conception Bay sediment larval index and the Bellevue Beach emergent larval index were used in the 1999 assessment (Nakashima and Evans 1999). The Bellevue Beach sediment larval index used in the 1999 assessment was excluded from the 2000 assessment. Estimates of sediment larvae and emergent larvae were highly correlated (Fig. 1) and the two life stages were less than 21 days apart raising concern that they were not independent. Consequently for this assessment only the Conception Bay sediment larval index and the Bellevue Beach emergent larval series were considered.

(g) Offshore 0-group and age 1 indices

An 0-group index and an age 1 index from annual offshore surveys conducted in August-September since 1994 (Anderson and Dalley 2000) were incorporated into the multiplicative cohort model for the first time in the 1999 assessment (Nakashima and Evans 1999). 0-group capelin were collected by bongos and age 1 capelin were collected using an IGYPT trawl during the offshore 0-group survey (Anderson and Dalley 2000).

(h) Canadian acoustic survey indices

Canadian acoustic surveys were conducted in the spring in Div. 3L from 1982-90, 1992, and 1996 and in the fall in Div. 2J3K from 1981, 1983-94. During initial development of the multiplicative model the spring (Winters 1995) and fall (Winters 1996) acoustic survey series were considered and their lack of correspondence to other series especially in the 1990s led to their rejection for inclusion in the original multiplicative model. With the development of the weighted model, these indices were included in the current run allowing the weightings to determine their influence on the multiplicative index rather than

the more subjective determination used in the mid 1990s (Winters 1995, 1996).

Model Development

Indices used in the weighted model are displayed in Figure 2. A Bayes update to better estimate the most recent yearclass (2000 in this example) is shown in Figure 3. Weightings are in Table 1. The final cohort model in Fig. 4 displays considerable variation, especially in recent years.

Summary

For the 2000 assessment, the weighted model was adopted to estimate standardized cohort abundance trends (Fig. 4). The relative size of the 1996 yearclass shows this yearclass to be relatively strong. Even at the lower 95% confidence interval the estimate is one of the highest in the series. However, there is considerable variation and therefore uncertainty about the estimate.

Based on the weighted multiplicative analysis, the 1996 yearclass is comparable to the 1986 yearclass but not as strong as the 1983 yearclass. The 1997 and 1998 yearclasses are weaker than the 1996 yearclass and appear to be of average strength. The 1999 yearclass will not be part of the 2000 spawning biomass, however, early indications from 0-group estimates suggest this yearclass may be one of the weaker yearclasses in the 1990s. The high variation surrounding the estimates, especially since 1993 partly reflects a reduction in the number of indices available to estimate relative yearclass size.

Besides the problems and assumptions associated with each of the indices in this analysis, there are other assumptions that have not been evaluated but may be important to interpreting the model results. For example, some indices do not use an independently derived age composition. Since 1996 the egg deposition and aerial survey indices use the same age composition derived from Bellevue Beach spawners. The results of the multiplicative analysis must be considered with caution in light of these and other assumptions whose effects have not been evaluated.

References

Anon. 1995. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70.

Anderson, J. T., E. L. Dalley, and D. J. Davis. 2000. Year-class strength of Northwest Atlantic capelin (2J3KLNO) estimated at the larval stage and age one based on the pelagic juvenile fish surveys, 1994-99. pp. . In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 00/.

Evans, G. T. 2000. Local estimation of probability distribution and how it depends on covariates. CSAS Res. Doc. 2000/120. 11p.

Lilly, G. R. 1995. Bycatches of capelin during autumn bottom trawl surveys in Divisions 2J3KLNO with emphasis on 1994. pp. 110-132. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70.

Myers, R. A., K. F. Drinkwater, N. J. Barrowman, and J. W. Baird. 1993. Salinity and recruitment of Atlantic cod (Gadus morhua) in the Newfoundland region. Can. J. Fish. Aquat. Sci. 50: 1599-1609.

Nakashima, B. S. 1998. Relative multiplicative trends in biomass, cohort abundance, and recruitment of capelin (Mallotus villosus). pp. 134-152. In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 98/63.

Nakashima, B. S. and G. T. Evans. 1999. Yearclass strength of capelin (Mallotus villosus) using a weighted multiplicative model. pp. 168-181. In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206.

Nakashima, B. S. and B. W. Slaney. 2000a. Spawning and early development of capelin (Mallotus villosus) at Bellevue Beach, Trinity Bay in 1999. pp. . In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 00/.

Nakashima, B. S. and B. W. Slaney. 2000b. The 1999 inshore capelin (Mallotus villosus) fishery in NAFO Div. 3KL. pp. . In: Anon. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 00/.

Winters, G. H. 1995. Interaction between timing, capelin distribution and biomass estimates from the Div. 2J3K capelin acoustic survey. pp. 167-192. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 95/70.

Winters, G. H. 1996. Further considerations of the age-structured multiplicative abundance model. pp. 81-108. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 96/90.

Winters, G. H., B. S. Nakashima, J. T. Anderson, and E. L. Dalley. 1996. The case for 0-group measures of capelin recruitment. pp. 109-126. In: Anon. Capelin in SA2 + Div. 3KL. DFO Atl. Fish. Res. Doc. 96/90.

Table 1. Weightings used in the multiplicative model. Survey symbols refer to indices in Appendix A.

Age	Survey	Weight
2	A	1.50
3	A	2.16
4	A	1.22
5	A	2.16
2	B	0.66
3	B	2.15
4	B	1.77
5	B	1.44
2	C	0.44
3	C	2.16
4	C	2.16
5	C	0.83
2	D	0.33
3	D	2.16
4	D	2.16
5	D	1.63
2	E	1.44
3	E	1.61
4	E	2.16
5	E	1.93
2	F	2.16
3	F	2.16
4	F	1.54
1	G	2.16
2	G	2.16
3	G	1.04
0	H	2.16
1	J	1.27
0	K	2.16
0	M	2.16
1	N	0.17
2	N	0.34
3	N	0.46
4	N	0.45
5	N	0.51
1	O	0.31
2	O	0.45
3	O	0.34
4	O	0.41
5	O	0.61

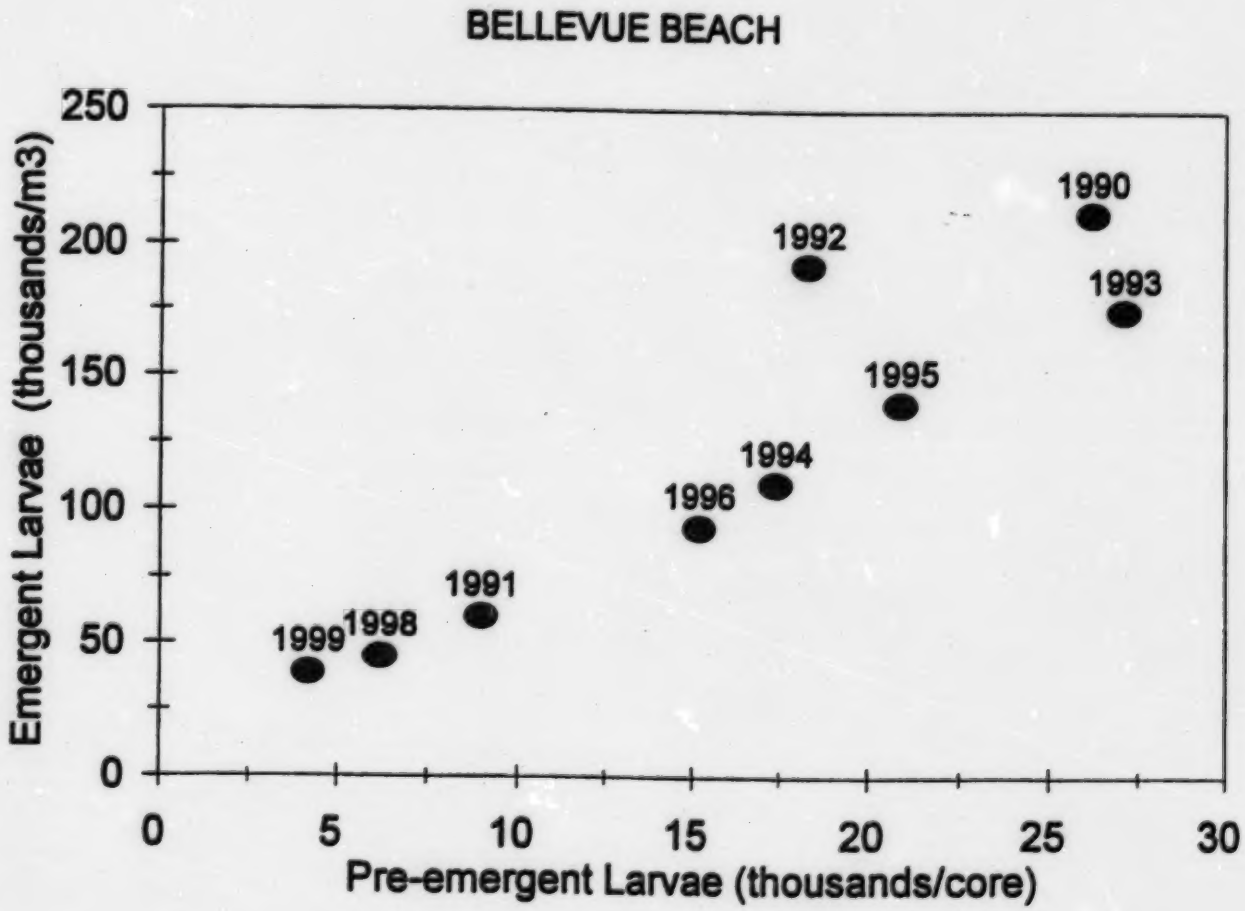

Fig. 1. Scatterplot of annual estimates of pre-emergent larvae and emergent larvae at Bellevue Beach (data from Nakashima and Slaney 2000a).

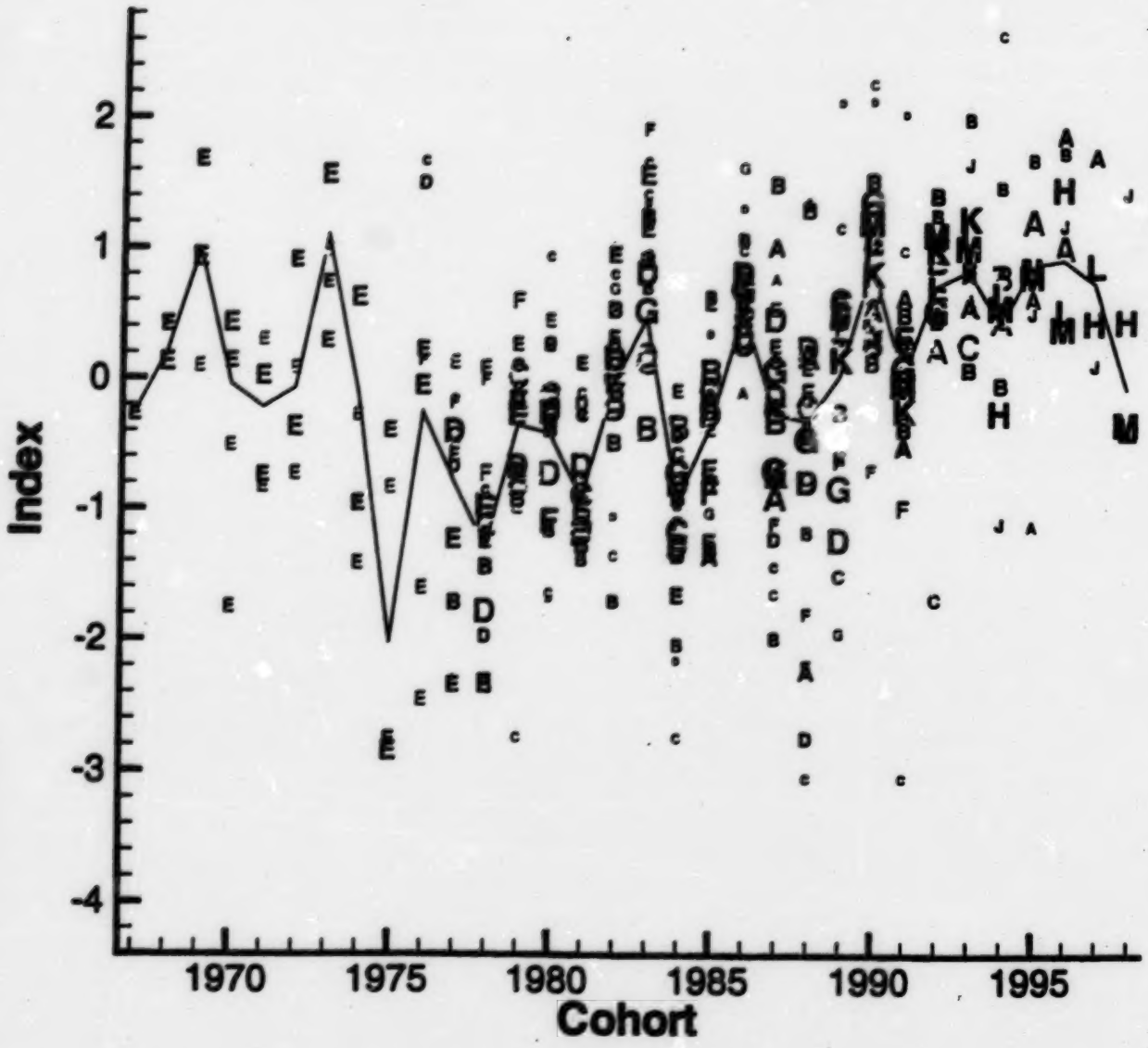

Fig. 2. The scatter of all indices used in the weighted multiplicative analysis. The letters refer to the indices in Appendix A. The larger the letter symbol the greater its contribution to the overall trend.

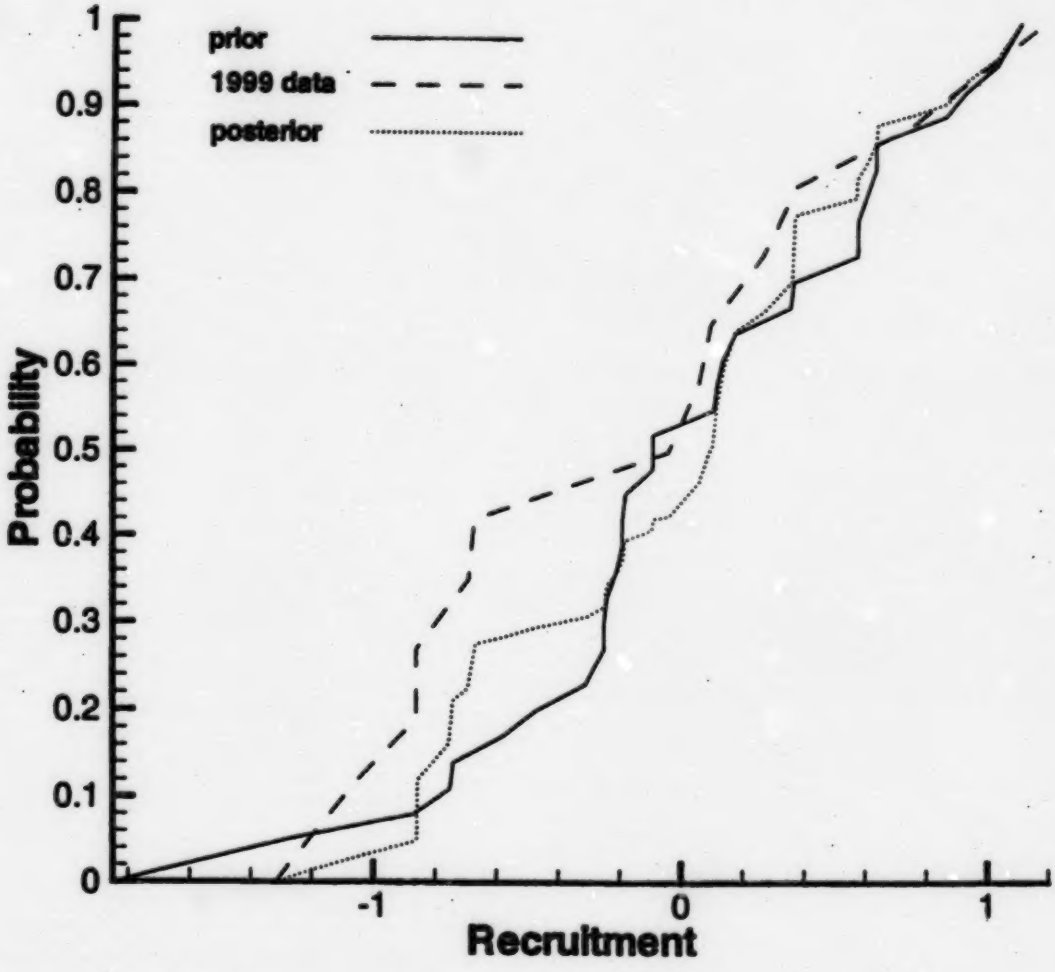

Fig. 3. Bayes update of the 1999 yearclass for the weighted multiplicative analysis.

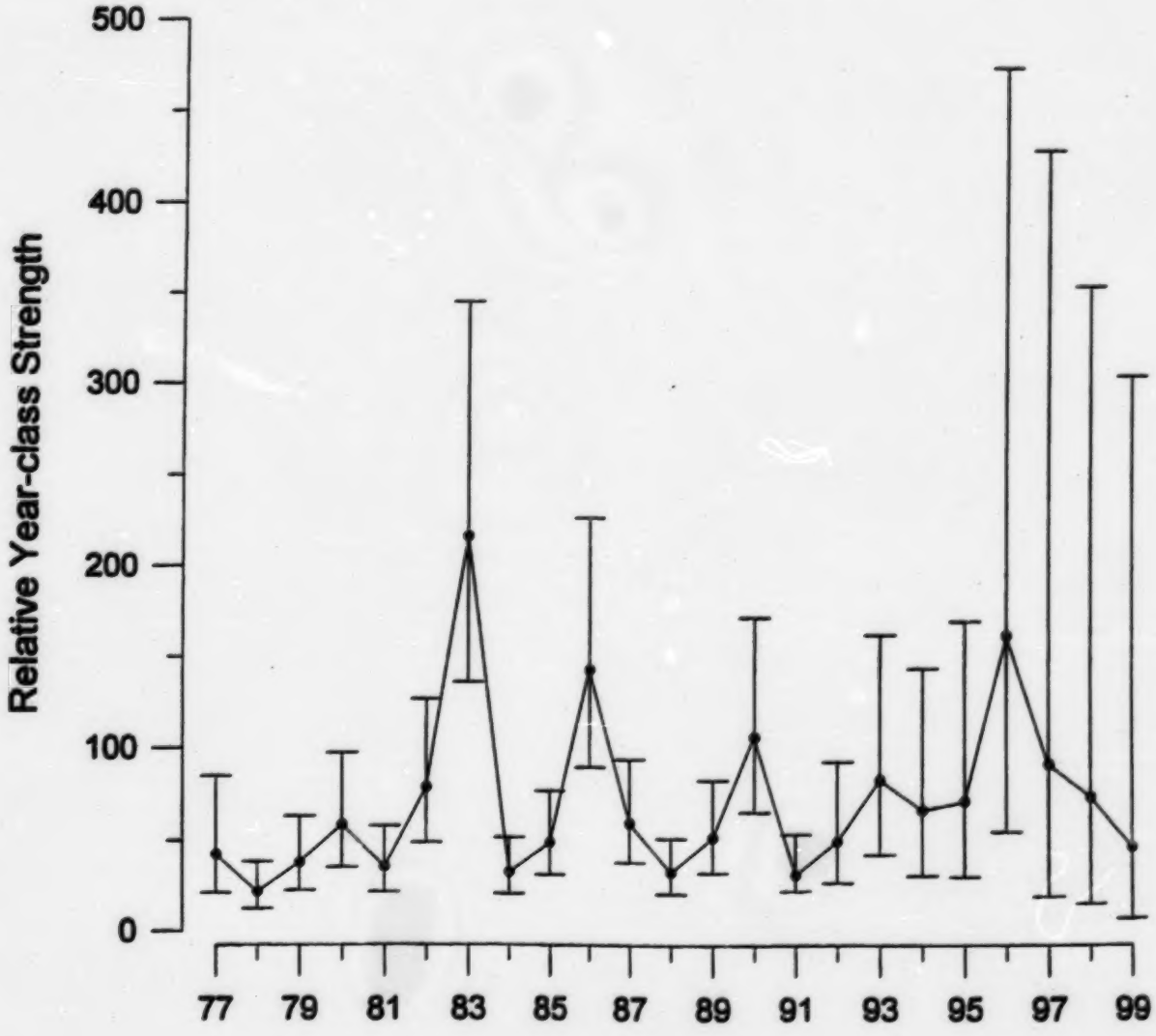

Fig. 4. Standardized estimates of cohort abundance of capelin with 2 standard errors using a weighted multiplicative model.

Appendix A. Indices used in the standardized cohort abundance model.

		Age					
	Year	0	1	2	3	4	5
Egg Deposition Index (A)							
	1990	-	-	12	184	156	12
	1991	-	-	179	544	374	84
	1992	-	-	152	563	669	129
	1993	-	-	213	1353	354	33
	1994	-	-	186	519	253	80
	1995	-	-	255	572	132	82
	1996	-	-	187	806	287	28
	1997	-	-	210	716	380	135
	1998	-	-	729	1537	395	82
	1999	-	-	618	1254	56	-
Aerial Survey Index (B)							
	1982	-	-	55	939	125	36
	1983	-	-	44	1783	1095	47
	1984	-	-	32	712	885	79
	1985	-	-	354	1775	582	143
	1986	-	-	23	1438	803	56
	1987	-	-	332	1456	4521	339
	1988	-	-	515	2247	527	500
	1989	-	-	24	3637	1011	52
	1990	-	-	54	1524	1987	54
	1991	-	-	-	-	-	-
	1992	-	-	505	2660	4798	887
	1993	-	-	226	2803	1013	130
	1994	-	-	625	2678	1480	328
	1995	-	-	1297	5227	2143	913
	1996	-	-	768	5514	2074	137
	1997	-	-	944	4662	3041	820
	1998	-	-	1000	4745	1255	217
Purse Seine Catch Rate Index (C)							
	1981	-	-		123	124	112
	1982	-	-	3	395	58	18
	1983	-	-	14	341	210	9
	1984	-	-	4	158	248	20
	1985	-	-	64	386	143	54
	1986	-	-	1	441	215	16
	1987	-	-	14	120	643	47
	1988	-	-	42	358	107	111
	1989	-	-	3	510	163	8
	1990	-	-	10	304	413	10
	1991	-	-	50	315	219	36
	1992	-	-	150	705	89	5
	1993	-	-	42	590	42	1
	1994	-	-	-	-	-	-
	1995	-	-	-	-	-	-
	1996	-	-	217	500	35	1

Appendix A. Continued ...

Year	Age 0	1	2	3	4	5
Trap Catch Rate Index (integrated) (D)						
1981	-	-	1	941	943	831
1982	-	-	16	1908	237	95
1983	-	-	67	1202	719	26
1984	-	-	30	766	1095	93
1985	-	-	334	1998	731	245
1986	-	-	10	3013	1674	155
1987	-	-	124	697	3216	243
1988	-	-	323	2271	634	615
1989	-	-	38	3447	1083	122
1990	-	-	55	2198	3200	83
1991	-	-	723	3180	2248	365
1992	-	-	730	4056	648	55
1993	-	-	665	4902	413	12
Russian 2J3K Fall Commercial Catch Rate Index (E)						
1972	-	-	33	181	59	8
1973	-	-	83	99	132	16
1974	-	-	92	223	80	56
1975	-	-	400	179	53	12
1976	-	-	46	437	36	5
1977	-	-	12	124	248	26
1978	-	-	38	71	97	14
1979	-	-	105	14	3	4
1980	-	-	206	185	49	7
1981	-	-	248	49	15	13
1982	-	-	247	61	5	1
1983	-	-	215	256	39	3
1984	-	-	262	77	39	5
1985	-	-	464	200	19	10
1986	-	-	128	419	50	4
1987	-	-	340	150	248	27
1988	-	-	430	112	14	33
1989	-	-	248	332	26	2
1990	-	-	208	281	95	3
1991	-	-	104	18	0	0

Appendix A. Continued ...

Year	Age 0	1	2	3	4	5
Groundfish 2J3K Fall Bycatch Index (F)						
1980	-	-	34	31	7	-
1981	-	-	77	26	5	-
1982	-	-	31	97	6	-
1983	-	-	-	-	-	-
1984	-	-	-	-	-	-
1985	-	-	-	-	-	-
1986	-	-	-	-	-	-
1987	-	-	39	23	41	-
1988	-	-	131	37	2	-
1989	-	-	-	-	-	-
1990	-	-	-	-	-	-
1991	-	-	166	49	2	-
1992	-	-	248	29	1	-
1993	-	-	128	87	9	-
1994	-	-	173	20	3	-
Groundfish 3L Fall Bycatch Index (G)						
1985	-	44	220	28	-	-
1986	-	-	-	-	-	-
1987	-	-	-	-	-	-
1988	-	45	261	5	-	-
1989	-	57	140	71	-	-
1990	-	-	-	-	-	-
1991	-	352	56	12	-	-
1992	-	99	466	2	-	-
1993	-	154	125	66	-	-
Offshore 0-group Index (H)						
1994	89987	-	-	-	-	-
1995	271008	-	-	-	-	-
1996	499665	-	-	-	-	-
1997	179281	-	-	-	-	-
1998	181884	-	-	-	-	-
1999	215480	-	-	-	-	-
Offshore age I Index (J)						
1994	-	21256	-	-	-	-
1995	-	1344	-	-	-	-
1996	-	6743	-	-	-	-
1997	-	13247	-	-	-	-
1998	-	4543	-	-	-	-
1999	-	16877	-	-	-	-

Appendix A. Continued …

Year	Age 0	1	2	3	4	5
Conception Bay Sediment Larval (K)						
1987	61	-	-	-	-	-
1988	-	-	-	-	-	-
1989	147	-	-	-	-	-
1990	285	-	-	-	-	-
1991	99	-	-	-	-	-
1992	340	-	-	-	-	-
1993	432	-	-	-	-	-
Bellevue Emergent Larval Index (M)						
1990	212	-	-	-	-	-
1991	61	-	-	-	-	-
1992	193	-	-	-	-	-
1993	175	-	-	-	-	-
1994	110	-	-	-	-	-
1995	140	-	-	-	-	-
1996	94	-	-	-	-	-
1997	-	-	-	-	-	-
1998	45	-	-	-	-	-
1999	39	-	-	-	-	-
Canadian 3L Spring Acoustic Survey (N)						
1982	-	.1	9.7	16.2	2.4	.9
1983	-	.1	3.4	1.9	.8	.1
1984	-	.1	21.0	6.2	3.1	.5
1985	-	.2	369.5	80.5	3.8	2.3
1986	-	.03	59.4	158.1	21.3	1.0
1987	-	.3	88.1	18.3	38.9	4.0
1988	-	13.6	380.4	65.7	9.7	16.8
1989	-	3.4	314.8	96.2	11.0	1.4
1990	-	18.9	353.2	169.0	55.6	1.9
1991	-	-	-	-	-	-
1992	-	-	19.0	6.5	.7	.1
1993	-	-	-	-	-	-
1994	-	-	-	-	-	-
1995	-	-	-	-	-	-
1996	-	.1	3.0	1.7	.1	.03

Appendix A. Continued ...

Year	Age 0	1	2	3	4	5
Canadian 2J3K Fall Acoustic Survey (O)						
1981	-	67.8	59.3	7.4	2.8	.7
1982	-	-	-	-	-	-
1983	-	2.6	2.5	1.3	.2	.03
1984	-	6.2	34.7	7.1	4.1	.4
1985	-	1.5	54.0	13.5	1.5	.6
1986	-	.1	6.6	12.1	1.1	.2
1987	-	.7	4.4	.5	.6	.1
1988	-	15.8	96.0	13.6	2.0	3.9
1989	-	1.9	59.0	35.3	2.5	.5
1990	-	1.4	2.6	1.6	.6	.1
1991	-	4.7	2.5	.4	.1	.1
1992	-	.1	1.9	.2	.1	.03
1993	-	.2	1.0	.3	.1	.03
1994	-	.3	.5	.1	.1	.03

Abundance and Biomass of Juvenile and Adult Capelin in the Newfoundland Region (NAFO 2J3KL) Estimated from the Pelagic Juvenile Fish Surveys, 1994-1999

by

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Introduction

The status of capelin (*Mallotus villosus*) within the Newfoundland Region (NAFO 2J3KL) is of interest to scientists and managers for many reasons. These include setting catch limits as part of the capelin management plan. Currently, a multiplicative model has been developed from a number of indices modelled over many years to assess the abundance of capelin. Results from the model indicate the population is similar to, or possibly larger than, the absolute estimates of capelin biomass available from the 1980's (Nakashima 1998). However, the model output does not agree with opinions of fixed gear fishermen (Anon. 1999a) and a number of the model assumptions appear to be violated (Anon. 1999b). These factors have brought into question the accuracy of the model output and highlighted the question, how many capelin are there?

Capelin are arguably the single most important component of the marine ecosystem off Newfoundland and Labrador, existing as the primary link between plankton production and piscivore consumption. Capelin are the primary prey of important apex predators, such as harp seals (*Phoca groenlandica*) and Atlantic cod (*Gadus morhua*) (Bundy et al. 2000). Total annual consumption of capelin could be on the order of 4.7 Mt. Capelin are also the primary consumer of production from the lower, primary and secondary producers, consuming on the order of 42 Mt annually (op. cit.). Current estimates of harp seal consumption within the Newfoundland region indicate that 710,000 t of capelin are consumed annually (Hammill and Stenson 2000) while consumption by cod may be only on the order of 100,000 t annually (Carscadden et al. 2001).

The purpose of this paper is to estimate the absolute abundance and biomass of capelin based on the mid-water IYGPT trawl used in the Pelagic Juvenile Fish Surveys carried out in 2J3KLNO 1994-1999 (Anderson et al. 2000). This survey extends from southern Labrador to the southern Grand Bank, including the inshore areas along the northeast coast of Newfoundland. We compare our estimates to an independent estimate based on acoustics (O'Driscoll et al. 2000) and evaluate our results in the context of the marine ecosystem.

Materials and Methods

The absolute abundance of capelin was estimated from the standardized catch at each station (number m^{-2}), correcting for IYGPT trawl catchability and night/day catch rate differences within three size categories of capelin: < 120 mm; 120-139 mm; ≤ 140 mm. These size ranges are thought to approximate the size ranges of age one, two and three year old capelin. The survey design is described in Anderson and Dalley (1997). Night/day ratios were estimated for each survey and each size range of capelin where IYGPT tows were designated as either night or day depending on the start time of each tow. Abundance offshore was based on the standardized catch rates at each station, as

$$N_1 = \sum_{i=1}^{k} q^{-1} \cdot A \cdot C_i \cdot D_i$$

where N_1 is the absolute number of capelin offshore, q is the trawl catchability, A is the area represented by each station (2.92×10^9 m^2), C_i is the density of capelin estimated at each station (m^{-3}), D_i is the maximum tow depth (m), and i represents the number of stations sampled offshore. For all inshore areas absolute abundance was estimated, as

$$N_2 = \sum_{j=1}^{m} q^{-1} \cdot B_j \cdot \sum_{i=1}^{k} E_i \cdot D_i$$

where N_2 is the absolute abundance inshore, q is the trawl catchability, B_j is the total area of each inshore area (m^2), E_i is the mean density of capelin for all stations sampled within each inshore area (m^{-3}), D_i is the mean maximum tow depth (m), i represents the number of stations within each inshore area, and j represents the inshore areas. The inshore areas were estimated using a high resolution shoreline to define the inner boundary, while the outer boundary was defined arbitrarily to include an outer extension of each bay onto the adjacent shelf. Area was estimated using Surfer (1999). Total abundance for the entire area was simply N_1+N_2. Catchability, q, was based on published estimates of nekton catchability by the IYGPT trawl (Koslow et al. 1997). They estimated an overall trawl catchability coefficient of 0.14, where published estimates have typically ranged from 0.1 to 0.25 (Sundby et al. 1989; Koslow et al. 1997).

Biomass was estimated based on the mean weight of capelin within each of the three size groups for each survey year. These weights were based on capelin samples collected during each survey and processed in the laboratory. Biomass for a given size group, for a given year was a simple multiple of the absolute abundance by the mean weight. The total population biomass was a summation of the three length groups.

Results

Capelin were consistently caught at higher abundance during the night, compared to the day, over all size groups for all years (Table 1). However, the night/day ratio varied without a consistent pattern, both among length groups and among years. As an average across all size groups within year, the ratio varied from a low of 4.87 in 1995 to a high of 25.64 in 1998. As an average for each size group across all years, the ratio was 19.22, 10.99, and 13.14 for size groups LG1, LG2 and LG3, respectively.

Mean length and weight of capelin within the three size groups tended to be greater beginning in 1997 (Table 2). Mean weight for all three size groups increased from 7.1 g in 1994-1996 compared to 9.1 g in 1997-1999. Among year abundance summed for all three size groups varied from a low of 6.6×10^{10} capelin in 1995 to a high of 9.4 x

10^{11} in 1994, based on a catchability coefficient of 0.14 (Table 3). Mean abundance was 5.6×10^{11} for all years, and ranged from 3.1×10^{11} to 7.9×10^{11}, based on high (0.25) and low (0.10) catchabilities respectively. Similarly, among year biomass ranged from 0.2 Mt in 1995 to 4.2 Mt in 1998, with a mean biomass estimate of 2.3 Mt, based on a catchability coefficient of 0.14 (Table 3). Mean biomass across all years ranged from 1.3 Mt to 3.2 Mt, based on high (0.25) and low (0.10) catchabilities (Table 3).

The year of highest abundance, 1994, was driven by the relatively strong 1993 year-class at age one. The 1996 year-class was also strong within the LG1 (age one) size group and this was particularly true for the LG2 (age two) size group in the 1998 survey. However, the very high value estimated at age two for the 1996 year-class was primarily due to the high night/day ratio applied (see Table 1). This in turn resulted in a high abundance and biomass estimate for the LG2 size group and ultimately the highest annual biomass estimate when all groups were combined (Table 3).

Discussion

There appear to be at least three different factors that determine the abundance and biomass estimates based on the mid-water trawl catches. Abundance each year appears to be determined primarily by year-class strength, where the 1993, 1996 and 1998 year-classes were relatively strong (Anderson et al. 2000). These strong year-classes resulted in the largest biomass estimates at age one (LG1), in excess of 2 Mt, which contributed the most to annual estimates of biomass.

A second effect appears to result from the night/day ratios, where relatively high ratios were applied for different length groups in some years. This effect appears to be most pronounced for all size groups in 1995 and for the LG2 size group in 1998. In 1998 for the LG2 size group, the largest night/day ratio in the series was applied to the relatively strong 1996 year-class at age two. This resulted in a LG2 biomass estimate of 2.3 Mt, an order of magnitude greater than estimated for any other year. We believe the high LG2 ratio applied to this relatively strong year-class resulted in an over estimate of population abundance and biomass in 1998. The night/day ratio for LG2 ranged from 1.65 to 17.2 for the other years, averaging 8.1. If this mean night/day ratio is applied to LG2 in 1998, abundance drops to 8.9×10^{10} from 2.8×10^{11} and the total biomass summed for all three size groups drops to 2.7 Mt, from 4.3 Mt. Similarly, if the mean night/day ratios estimated for all years are applied to the three length groups in 1995 then total abundance is estimated as 3.9×10^{11} and we calculate a total biomass of 1.3 Mt. Applying these simple corrections to the night/day ratios, it would appear that the total biomass of capelin estimated during the trawl surveys might range from 0.9 to 2.9 Mt during the period 1994-1999.

A third factor affecting the biomass estimates is the increase in mean weight of capelin 1994-1996 compared 1997-1999. The increase was approximately 30%, which explains in part the higher biomass estimates during the final three years.

During the 1999 pelagic juvenile fish survey an acoustic survey was carried out to estimate the spatial distribution of capelin between survey stations and throughout the water column (O'Driscoll et al. 2000). Total acoustic biomass estimated from this survey was only 43,000 t to 69,000 t, depending on the target strength model used (op. cit.). These acoustic estimates represent only 2-3% of the biomass estimate based on the trawl survey. Recently, Carscadden et al. (2001) estimated that approximately 1.9 Mt of capelin

would be consumed annually in the 1990's based on a set of predators that included harp seals (710,000 t), cetaceans (700,000 t), seabirds (240,000 t), Greenland halibut (150,000 t) and Atlantic cod (100,000 t). For this level of predation to exist, we should expect in excess of 2 Mt of capelin to occur on average. Therefore, the acoustic estimate appears to be a significant under-estimate of the true biomass of capelin that must occur in the waters off Newfoundland.

The application of night/day ratios to our capelin catches is based on the simple assumption that capelin undergo diurnal migrations into the trawl zone (< 60 m) during night. Characteristically, capelin occur in layers near the surface at night and form schools in midwater and near the bottom during the day (O'Driscoll et al. 2000). We know there are interannual variations in diurnal behaviour (Shackell et al. 1994) as well as seasonal (O'Driscoll and Rose 1999) and that behaviour can vary spatially within the survey (O'Driscoll et al. 2000). Diurnal catch rate differences result primarily from migration into surface waters by night and out by day, but are also due to dispersion at night and schooling by day and can vary with season (Bailey et al. 1977, O'Driscoll and Rose 1999).Our survey results support these observations, with the additional caveat that diurnal variation also appears to vary among size classes (i.e. ages). However, the application of our ratios to correct for day catches appears to be too simplistic a solution to apply in all cases. We believe that a more direct method utilizing acoustics is necessary to properly correct for the amount of capelin within the trawl zone.

Our estimates of absolute abundance and biomass should compare most closely to the acoustic survey estimates carried out in fall 1983-1994, where both surveys were post-spawning and covered a wide area of the shelf from southern Labrador to the northern Grand Bank. However, our estimates appear to be closer to the spring acoustic survey than the fall (Figure 1). In general, we should expect our abundance estimates to be higher than the previous fall acoustic estimates due to our greater potential to capture one year old juvenile capelin. In addition, our estimates include the inshore areas which were not surveyed by previous acoustic surveys. On average, the inshore areas represented about 40% of all capelin captured within the 2J3KL zone.

It appears that the Pelagic Juvenile Fish Survey holds promise as a basis for estimating the absolute abundance and biomass of capelin off Newfoundland. Our estimate that approximately 0.9 Mt to 2.9 Mt of capelin have occurred in recent years is similar to, and generally greater than, fall acoustic estimates in the 1980's. Limitations imposed by sampling the surface layer can be addressed by simultaneously using acoustics, as carried out in 1999 (O'Driscoll et al. 2000). Diurnal behaviour of capelin must be addressed by a comprehensive research program, both as this behaviour affects trawl catchabilities and diurnal corrections and as it affects acoustic detectability. Finally, questions regarding the inshore distribution of capelin and the assumption that the present survey design is adequately sampling capelin must also be addressed. Incorporating acoustics within the existing survey design, combined with separate sampling programs directed at identified concentrations inshore and offshore should result in our capability to realistically assess the status of capelin within the Newfoundland region.

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References

Anderson, J. T., and E. L. Dalley. 1997. Distribution and abundances of pre-recruit capelin (*Mallotus villosus*) in the Newfoundland region, 1991-1996. **In** Capelin in SA2 + Div. 3L. Chapter 7. DFO Canadian Stock Assessment Secretariat Res. Doc. 97/29. p. 125-147.

Anderson, J. T., Dalley, E. L., and Carscadden, J. E. 1999. Absolute abundance and biomass of juvenile and adult capelin (*Mallotus villosus*) in the Newfoundland Region (2J3KLNO) estimated from the Pelagic Juvenile Fish Surveys, 1994-1998. **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206. p. 112-125.

Anderson, J. T., Dalley, E. L., and Davis, D. J. 2000. Year-Class strength of northwest Atlantic capelin (2J3KLNO) estimated as 0-Group (larval), 1-Group and 2+-Group stages from the Pelagic Juvenile Fish Surveys, 1994-1999. **In** Capelin SA2 + Div. 3KL. CSAS Res. Doc. 2000/xxx. 20 p.

Anonymous. 1999a. Capelin in Subarea 2 + Div. 3KL. CSAS Stock Status Report B2-02 (1999). 9 p.

Anonymous. 1999b. Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206. p. xxvii.

Bailey, R. F. J., Able, K. W., and Leggett, W. C. 1977. Seasonal and vertical distribution and growth of juvenile and adult capelin (*Mallotus villosus*) in the St. Lawrence estuary and western Gulf of St. Lawrence. J. Fish. Res. Board Can. 34: 2030-2040.

Carscadden, J. E., Frank, K. T., and Leggett, W. C. 2001. Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. Can. J. Fish. Aqaut. Sci. 58: 73-85.

Hammill, M. O. and Stenson, G. B. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. J. Northwest Atl. Fish. Sci. 26: 1-23.

Koslow, J. A., Kloser, R. J., and Williams, A. 1997. Pelagic biomass and community structure over the mid-continental slope off southeastern Australia based upon acoustic and midwater trawl sampling. Mar. Ecol. Prog. Ser. 146: 21-35.

Nakashima, B. 1998. Relative multiplicative trends in biomass, cohort abundance, and recruitment of capelin (Mallotus villosus). **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 98/63. p. 134-152.

O'Driscoll, R. L., and Rose, G. A.1999. Seasonal changes in abundance, distribution and vertical migration of capelin in Placentia Bay. **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206. 182-195.

O'Driscoll, R. L., Anderson, J. T., and Mowbray, F. 2000. Abundance and distribution of capelin from an acoustic survey in conjunction with the 1999 pelagic juvenile survey. **In** Capelin in SA2 + 3KL. CSAS Res. Doc. 2000/xxx. 27 p.

Shackell, N. L., Carscadden, J. E., Miller, D. S. 1994. Diel vertical migration of capelin (*Mallotus villosus*) and its effect on acoustic estimates of density. ICES Coun. Meeting Report 1994/Mini:5 18 p.

Sundby, S., Bjorke, H., Soldal, A. V., and Olsen, S. 1989. Mortality rates during the early life stages and year-class strength of northeast Arctic cod (*Gadus morhua*). Rapp. P.-v. Reun. Cons. Int. Explor. Mer 191: 351-358.

Surfer. 1999. Surface mapping system. Version 7. Golden Software Inc., 809 14th Street, Golden, Colorado. 80401-1866.

Table 1. Ratio of night to day capelin densities (number m-3) for each year and each size group, where LG1 is 55-119 mm, LG2 is 120-139 mm and LG3 is ≥140 mm.

Year	LG 1	LG 2	LG 3
1994	9.62	12.03	4.10
1995	2.96	7.96	3.68
1996	53.38	17.20	4.91
1997	2.15	1.65	14.96
1998	4.26	25.42	49.24
1999	44.97	1.65	1.95

Table 2. Mean length (mm) and weight (g) of capelin within three size categories sampled by the IYGPT in the Pelagic Juvenile Fish Surveys, 1994-1999. LG1 – length group 55-119 mm; LG2 – length group 120-139 mm; LG3 – length group ≥ 140 mm; WG1, WG2, WG3 – weight for LG1, LG2, LG3. Sample numbers are in parentheses.

Year	LG1	LG2	LG3	WG1	WG2	WG3
1994	92.6 (389)	127.6 (85)	152.1 (36)	2.9	7.6	12.5
1995	99.7 (239)	127.7 (61)	142.0 (4)	3.2	7.3	8.8
1996	90.9 (330)	131.1 (27)	149.0 (33)	2.5	8.4	11.1
1997	97.9 (331)	129.9 (122)	149.5 (79)	3.5	8.9	14.9
1998	101.9 (226)	129.3 (139)	149.4 (78)	3.7	8.3	15.4
1999	96.4 (292)	128.3 (62)	154.7 (38)	3.3	8.8	14.8

Table 3. Absolute abundance and biomass (t) estimates for capelin length groups 1-3 caught in the IYGPT trawl during annual Pelagic Juvenile Fish Surveys in 2J3KLNO, 1994-1999.

	Q=0.14							
Year	Group 1		Group 2		Group 3		Total Po	Total Bio
	Population	Biomass (t)	Population	Biomass (t)	Population	Biomass (t)		
1994	9.20E+11	2,669,112	1.94E+10	147,247	2.67E+09	33,448	9.42E+11	2,849,806
1995	5.76E+10	184,306	7.65E+09	56,130	4.81E+08	4,249	6.57E+10	244,686
1996	3.19E+11	810,155	5.63E+09	47,444	7.54E+09	83,668	3.32E+11	941,267
1997	6.18E+11	2,151,376	2.87E+10	254,292	2.00E+10	296,534	6.67E+11	2,702,202
1998	2.65E+11	969,562	2.79E+11	2,304,168	6.37E+10	981,481	6.07E+11	4,255,211
1999	7.23E+11	2,385,900	2.57E+10	226,160	3.12E+09	46,176	7.52E+11	2,658,236
						Mean	5.61E+11	2,275,235

	Q=0.10							
Year	Group 1		Group 2		Group 3		Total Po	Total Bio
	Population	Biomass (t)	Population	Biomass (t)	Population	Biomass (t)		
1994	1.29E+12	3,736,757	2.71E+10	206,146	3.74E+09	46,825	1.32E+12	3,989,728
1995	8.06E+10	258,029	1.07E+10	78,582	6.74E+08	5,949	9.20E+10	342,561
1996	4.47E+11	1,134,217	7.89E+09	66,422	1.06E+10	117,135	4.65E+11	1,317,774
1997	8.65E+11	3,011,926	4.02E+10	356,009	2.79E+10	415,148	9.34E+11	3,783,082
1998	3.71E+11	1,357,386	3.90E+11	3,225,836	8.92E+10	1,374,073	8.50E+11	5,957,295
1999	1.01E+12	3,340,260	3.60E+10	316,624	4.37E+09	64,646	1.05E+12	3,721,530
						Mean	7.85E+11	3,185,328

	Q=0.25							
Year	Group 1		Group 2		Group 3		Total Po	Total Bio
	Population	Biomass (t)	Population	Biomass (t)	Population	Biomass (t)		
1994	5.15E+11	1,494,703	1.08E+10	82,458	1.49E+09	18,730	5.28E+11	1,595,891
1995	3.23E+10	103,212	4.28E+09	31,433	2.69E+08	2,380	3.68E+10	137,024
1996	1.79E+11	453,687	3.16E+09	26,569	4.22E+09	46,854	1.86E+11	527,109
1997	3.46E+11	1,204,770	1.61E+10	142,403	1.12E+10	166,059	3.73E+11	1,513,233
1998	1.48E+11	542,955	1.56E+11	1,290,334	3.57E+10	549,629	3.40E+11	2,382,918
1999	4.05E+11	1,336,104	1.44E+10	126,650	1.75E+09	25,859	4.21E+11	1,488,612
						Mean	3.14E+11	1,274,131

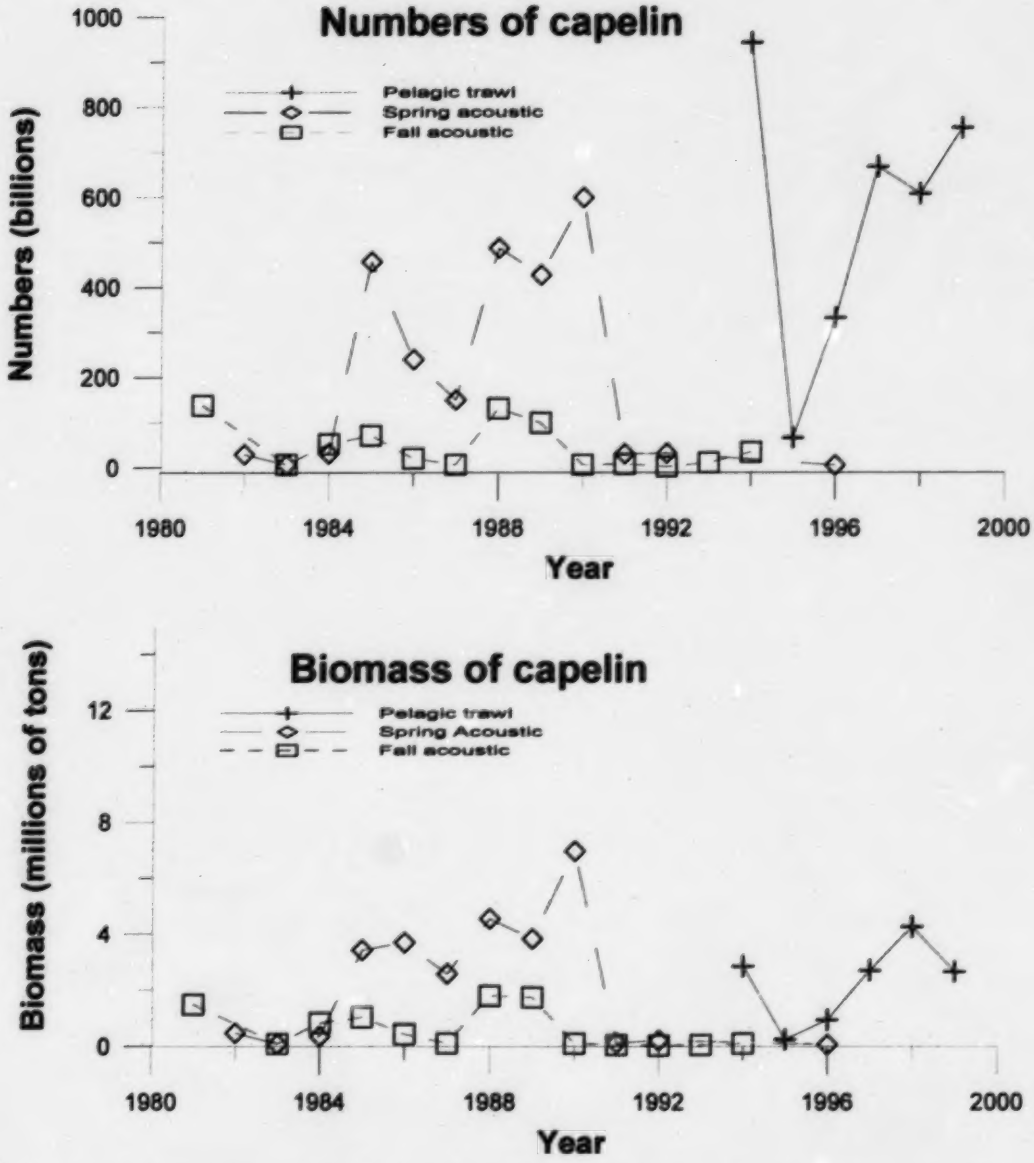

Figure 1. Estimates of capelin abundance (top) and biomass (bottom) based on acoustic surveys in spring (1982-92, 1996) and autumn (1981-94) and pelagic trawl surveys (1994-99), in the Newfoundland Region.

Year-Class Strength of Northwest Atlantic Capelin (2J3KLNO) Estimated as 0-Group (larval), 1-Group and 2+-Group Stages from the Pelagic Juvenile Fish Surveys, 1994-1999

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Abstract

Introduction

Research trawl surveys to estimate the year-class strength of capelin within NAFO Divisions 2J3KLNO have been carried out since 1991 (Anderson and Dalley 1995, 1996, 1997, 1998, 1999). Two gear types are used to sample larval and juvenile capelin in the upper water column. This is a multi-species survey carried out at the end of August and early September, timed to sample pelagic juvenile cod before they settle to the bottom and to sample larval capelin released from beach and bottom sediments following the primary spawning period in June and July.

The purpose of this paper is to report on the abundance and distribution of larval and juvenile capelin from the 1999 survey, and to compare these results to the previous surveys carried out 1994-1998. In addition, we examined the relationship between abundance measured at the larval stage to abundance measured for age one (1-group) and two (2+-group) juvenile capelin. Materials and methods used in this project have been previously described by Anderson and Dalley (1995, 1996, 1997, 1998) and Anderson et al. (1999b).

Results & Discussion

1999 Survey

The survey was conducted from August 23 to September 19, 1999 (Table 1). In 1999, 129 stations were sampled with the bongo and IYGPT samplers. These stations covered the inshore areas along the northeast coast of Newfoundland and six offshore areas over the Northeast Newfoundland Shelf and on the Grand Banks (Figure 1). The 1999 survey was again plagued by ship problems, where the Templeman was unavailable

due to refit problems until September 12. The Teleost sampled the northern portion of the survey area, from Bonavista Peninsula north, and then proceeded to sample the southern portion of the survey, working from Trinity Bay and Conception Bay then from north to south on the Grand Banks. The Templeman sampled only the southern Grand Bank area. Due to time constraints, the outer northern portion of the Grand Bank was not sampled in 1999 (Nose Index Area, Figure 1).

Abundance Indices Ages 0 and 1 and 2+ Capelin

Abundance indices are reported for larval capelin captured in the bongo sampler as well as for length groups corresponding to one year old capelin (1-group) and capelin which are two years of age and older (2+-group) for all index areas and then summarized for inshore, offshore and all areas combined. In addition, we report for the first time an abundance index for 0-group capelin captured by the IYGPT. Due to strong night/day differences observed in juvenile capelin captured in the IYGPT, we applied a correction to all day samples based on the night/day ratio estimated each year (Anderson et al. 1999a). Both corrected and non-corrected indices are reported (Tables 2 and 3). Bonavista Bay was not sampled in 1998, due to the early recall of the research ship Teleost.

Previously, Bonavista Bay has been an important index area for capelin at both the larval stage and at the juvenile stages. We compared the ratio of abundance measured in Bonavista Bay to the total for the other inshore areas (Conception Bay, Trinity Bay, Notre Dame Bay, White Bay) for the previous four survey years, 1994-1997. For larvae, the mean ratio was 0.183 (Std Dev 0.0628, CV 34.4%). We felt this ratio was stable enough over the previous four years that it could be used to estimate the abundance of capelin larvae in the Bonavista Bay Index Area for 1998. Therefore, we have used this ratio in the estimate for the WIA (Table 3). Compared to the overall (i.e. total) estimate where Bonavista Bay was left not sampled, the predicted value increased the total WIA for 1998 by 7.0%. This increase had the effect of increasing the 1998 larval abundance index to a value similar to the 1997 year-class.

For age one capelin (LG1), the ratio of Bonavista Bay to the other inshore areas averaged 15.84 (range 0.007-77.6). The huge range among years indicates that estimating abundance in Bonavista Bay in 1998 based on the mean ratio would increase the total abundance estimate by 31.2%. However, this increase would not change the year-class strength ranking, where the 1997 year-class at age one would still rank fourth. Similarly for age 2+ capelin (LG2), the ratio of Bonavista Bay to the other inshore areas averaged 3.12 (range 0.003-15.34). Applying this ratio to estimate Bonavista Bay abundance in 1998 results in an increase of total abundance by 9.1% and has no overall effect on year-class ranking. We have chosen to correct for capelin abundance in Bonavista Bay in 1998 for the LG1 and LG2 size classes based on the mean abundance measured in the other four inshore areas in 1998. This is a conservative estimate, increasing the total abundance estimates by 2.3% and 2.8%, respectively. These estimates have no effect on year-class strength ranking, yet the correction moves the total estimates for the inshore and total abundance values more closely to what it might have been if we had actually sampled Bonavista Bay in 1998.

Abundance of larval capelin sampled by the bongo was marginally higher in 1999 than 1997 and 1998, but much lower than the maximum value reported in 1996 (Figure

2). The inshore index was notably higher than the offshore index in 1999, as compared with previous years. Abundance of larval capelin captured in the IYGPT was one to two orders of magnitude greater than previous years (Figure 3). When the bongo and IYGPT larval indices were added the total index was marginally greater in 1995 and 1997 and more than doubled in 1999 (Figure 3). Few larvae were taken in the IYGPT in the other three years.

Abundance estimated for 1-group capelin in 1999 was the second highest in the time series for year-classes 1993-1998 (Figure 4). The notable difference in 1999 was the highest index for the inshore area. Offshore, abundance for the 1998 year-class was similar to that for 1996, but much lower than that estimated for the 1993 year-class.

Comparison of the larval index to the 1-group index demonstrated a very close relationship for the 1994-1998 year-classes for non-corrected data (Figure 5). The relationship was also quite good for the corrected data with the exception of the 1998 year-class that was estimated to be much higher at age one than measured as larvae. This deviation suggests that the night/day correction for 1998 may be in error, where we have over estimated the abundance by the correction factor. These relationships are statistically significant explaining 77.3% and 99.7% of the variation, respectively.

The larval index also demonstrated a highly significant relationship to abundance estimated for the 2+ length group for the 1994-1997 year-classes (Figure 6). Previously, it has been demonstrated that capelin > 120 mm length are comprise primarily of two year old capelin, with variable mixtures of age one, three and even four year old capelin. The close relationship between the larval index with the 2-group index implies that year-class strength established early in life carried through to age two capelin. Here we assume that the abundance of the 2+ length group is primarily determined by age two capelin. There was no difference in the relationship between larval and age two capelin for corrected and non-corrected data. Again, the relationships are statistically significant explaining 89.1% and 89.3%, respectively.

Together, these comparisons demonstrate that year-class strength in capelin was established early in life, within days to weeks of larval release from beach sediments. These observations are consistent with the prediction of Leggett et al. (1984) and Carscadden et al. (2000) that release from beach sediments and early survival as larvae are important determinants of survival and ultimately year-class strength in northwest Atlantic capelin.

Size of Capelin

Mean length of capelin in the bongos was 13.2 mm, range 5-29 mm, which was larger than mean lengths of 8.9-11.7 mm, 1994-1998 (Figure 7). If growth rates were not different among years, then a larger length implies an earlier spawning time. Prior to 1999, small numbers of larval capelin were captured in the IYGPT. In 1999, large numbers were caught with a mean length of 28.5 mm, ranging from 14 mm to 47 mm (Figure 7). This is smaller than previous years when mean length ranged from 34-35 mm in 1995 and 1997 for sample sizes of 262 and 43 fish, respectively. Mean length was 33.7 mm in 1994 and 42.8 mm in 1996, although these are based on sample sizes of only 4 fish each year. Previously, we demonstrated that bongos sampled larval capelin up to about 23 mm in length and the IYGPT sampled larval capelin down to about 25 mm in

length (Anderson and Dalley 1995). The split in the apparent bimodal distribution occurred within the length range not well sampled by either gear. Therefore, the length frequency distribution of larval capelin may in fact be unimodal. The combined data sets clearly demonstrate that spawning and larval release occurred much earlier in 1999 than any previous year in the 1990's, given the previous assumption of similar growth rates.

Distribution of Larvae and Juveniles and Adults

Capelin larvae were distributed along the northeast coast of Newfoundland, as in previous years, with some larvae observed offshore on the northern Grand Bank (Figure 8). Larval capelin were captured only at one station on the southern Grand Bank in 1999, although we note that two stations directly north of the southern Grand Bank area, which might have contained larvae, were not sampled in 1999 due to poor weather. The presence of capelin on the southern Grand Bank is consistent with spawning in this area, although at a very low level. No capelin were observed off southern Labrador, in contrast to 1998 when small numbers of larvae were encountered there (Anderson et al. 1999).

Large larval capelin, primarily 20-40 mm, were more widely distributed in 1999 than in previous years (Figure 9). Previously, these large larval capelin were observed sporadically inshore with occasional small catches offshore and these distributions were always embedded within the broader distribution of larval capelin sampled by the bongo. In 1999, the presence of a fairly continuous distribution of large larval capelin offshore in the vicinity of Funk Island Bank is indicative of spawning to the north, possibly including coastal Labrador. The biggest concentration of these large larvae occurred in the Avalon Channel which would be consistent with spawning along the northeast coast and a southward drift of larvae in the Labrador Current.

Juvenile capelin, primarily age one, occurred most abundantly offshore on the northern Grand Bank and on Funk Is. Bank (Figure 10). The largest single catch occurred in Conception Bay and high abundance also occurred in Notre Dame Bay. A small concentration was observed on the SE Shoal of the southern Grand Bank. 1-group capelin were also observed off southern Labrador at relatively high abundance compared to previous years. Failure to sample the outer northern Grand Bank (i.e. the Nose) prevents any interpretation of how far offshore the distribution of 1-group capelin extended. Overall, the impression is one of a wider offshore distribution in 1999 extending from the northern Grand Bank to southern Labrador.

The distribution of 2-group capelin was decidedly northward and offshore compared to previous years, where highest abundance occurred over Funk Is. Bank (Figure 11).

Spawning Times

The presence of large larval capelin at relatively high abundance in 1999 indicates there was a significant early spawning in 1999. If we assume growth rates of 0.25 – 0.35 mm d^{-1} (Jacquaz et al. 1977, Frank and Carscadden 1989), then these larval capelin averaged 70-100 days age. Based on a mid survey date of day 148, this would back calculate to release from beach sediments between days 148-177, which corresponds roughly to the last week of May through to the third week of June. Depending on beach

incubation temperatures, this implies spawning from early May through to early June. As it is unlikely that a significant spawning occurred along the coast in early May, we suspect that the lower growth rate is inappropriate for these capelin. The presence of larval capelin in the IYGPT trawls in previous years indicates that some early spawning has occurred during the period 1994-1998. However, the extent of early spawning was much greater in 1999. Similarly for capelin larvae sampled in the bongo, which averaged 13.2 mm length, release from beach sediments would have occurred between days 209-220, which corresponds to the end of July into the first two weeks in August. Therefore, if we restrict the back calculation estimates to the higher growth rates, we estimate that release from beach sediments occurred primarily from the third week of June to the second week of August.

The mean velocity of the Labrador Current at the surface is 0.2 m sec^{-1} while velocities off Bonavista Bay averaged 0.3 m sec^{-1} over a one month period (Petrie and Anderson). Velocity over the Grand Bank is typically weak, ranging from 0.02-0.1 m sec^{-1} (op. cit.). At drift speeds of 0.2 m sec^{-1} and times since release of 70 days, then these larvae could have drifted on the order of 1,200 km at the time of capture. Therefore, large larvae sampled offshore on Funk I. Bank and the northern Grand Bank could have spawned far to the north.

References

Anderson, J. T., and E. L. Dalley. 1995. Distribution and abundances of pre-recruit capelin (*Mallotus villosus*) in the Newfoundland region, 1991-94. **In** Capelin in SA2 + Div. 3L. Chapter 9. DFO Atl. Fish. Res. Doc. 95/70. P. 133-145.

Anderson, J. T., and E. L. Dalley. 1996. Distribution and abundances of pre-recruit capelin (*Mallotus villosus*) in the Newfoundland region, 1994 and 1995. **In** Capelin in SA2 + Div. 3L. Chapter 14. DFO Atl. Fish. Res. Doc. 96/90. P. 185-199.

Anderson, J. T., and E. L. Dalley. 1997. Distribution and abundances of pre-recruit capelin (*Mallotus villosus*) in the Newfoundland region, 1991-1996. **In** Capelin in SA2 + Div. 3L. Chapter 7. DFO Canadian Stock Assessment Secretariat Res. Doc. 97/29. P. 125-147.

Anderson, J. T., and E. L. Dalley. 1998. Year-class strength of northwest Atlantic capelin (2J3KLNO) estimated from pelagic juvenile fish surveys in the Newfoundland Region, 1991-97. **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 98/63. P. 114-133.

Anderson, J. T., E. L. Dalley, and J. E. Carscadden. 1999a. Absolute abundance and biomass of juvenile and adult capelin (Mallotus villosus) in the Newfoundland region (2J3KLNO) estimated from the Pelagic Juvenile Fish Surveys, 1994-1998. **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206. P. 112-125.

Anderson, J. T., E. L. Dalley, and D. J. Davis. 1999b. Year-class strength of northwest Atlantic capelin (2J3KLNO) estimated at the larval stage and age one based on the

pelagic juvenile fish surveys, 1994-1999. **In** Capelin in SA2 + Div. 3KL. CSAS Res. Doc. 99/206. P. 126-141.

Carscadden, J. E., K.T. Frank, and W. C. Leggett. Evaluation of an environment – recruitment model for capelin (*Mallotus villosus*). ICES J. Mar. Sci. 57: 412-418.

Frank, K. T., and J. E. Carscadden. 1989. Factors affecting recruitment variability of capelin (Mallotus villosus) in the Northwest Atlantic. J. Cons. int. Explor. Mer 45: 146-164.

Jacquaz, B., K. W. Able, and W. C. Leggett. 1977. Seasonal distribution, abundance and growth of larval capelin (*Mallotus villosus*) in the St. Lawrence estuary and northwestern Gulf of St. Lawrence. J. Fish. Res. Board Can. 34: 2015-2029.

Leggett, W. C., K. T. Frank, and J. E. Carscadden. 1984. Meteorological and hydrographic regulation of year-class strength in capelin (*Mallotus villosus*). Can. J. Fish. Aquat. Sci. 41: 1193-1201.

Petrie, B., and C. Anderson. 1983. Circulation on the Newfoundland continental shelf. Atmos.-Ocean 21: 207-226.

Table 1. Summary of Pelagic Juvenile Fish Surveys conducted, 1994-1999. Bongo – refers to the number of stations sampled with a bongo plankton net; IYGPT – refers to the number of stations sampled with an IYGPT mid-water trawl; DoY – refers to the calendar day of the year.

Year	Ship-Trip	Dates	DoY Start	DoY End	DoY Middle	Bongo	IYGPT
1994	TEM157/GAD247	22 Aug-3 Sep	234	246	241	99	99
1995	TEM175/TEL018	5 Sep -22 Sep	248	264	257	139	139
1996	TEM193/TEL034	19 Aug-6 Sep	231	249	241	147	147
1997	TEM210/TEL050	11 Aug-29 Aug	223	241	233	148	148
1998	TEM226/TEL069	24 Aug-10 Sep	236	253	244	132	132
1999	TEM242/TEL081	23 Aug-19 Sep	234	261	248	129	127

Table 2. Abundance indices of Northwest Atlantic capelin (2J3KLNO) based on the two-ship surveys, 1994-1999, using the Weighted Index Area method (number m^{-3} 10^3 Bongo and 10^5 IYGPT). * - indicates estimated value, see text for details.

	Sampling Year 1994				Sampling Year 1995				Sampling Year 1996			
Area	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group
Inshore												
CB	7603.79	0.06	2151.73	39.54	27625.12	0.00	6.62	1.53	52170.22	0.50	6.42	0.21
TB	3707.05	0.00	256.49	11.19	13790.88	0.11	8.48	1.04	35482.76	0.00	24.29	0.50
BB	4615.61	0.00	1067.86	5.82	13439.62	0.39	7.74	1.36	37052.02	0.19	3216.28	249.36
NDB	16803.24	0.00	45.93	2.21	19476.80	59.47	234.53	6.19	45499.36	0.00	12.04	0.34
WB	17589.24	0.19	34.44	0.69	7671.55	0.12	1.59	5.[illegible]	57666.52	0.18	4.70	0.21
SUM	52870.73	0.19	3557.91	109.45	82175.97	60.09	261.03	15.07	236000.68	0.37	3257.73	265.64
Offshore												
HB					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISN					4911.18	0.98	0.00	17.57	0.00	0.00	0.16	0.16
ISS	26061.33	0.50	50.95	0.00	34173.76	0.00	14.64	5.16	196751.14	0.40	0.62	0.17
BIBI					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIBO												
FIBI					5606.14	0.00	0.31	6.71	3201.03	0.00	1796.45	7.06
FIBO												
NGB	9181.50	0.31	16834.73	275.27	143667.73	11.22	718.60	144.36	63703.69	0.00	1976.37	33.79
SA	8064.32	0.00	219.38	63.95					14021.44	0.00	16.95	0.48
SGB	53.28	0.00	812.65	35.35	973.66	0.60	341.09	12.71	0.00	0.00	0.00	0.00
NOSE									0.00	0.00	606.74	0.66
TAIL												
SGBO												
WD												
SUM	37316.11	0.81	17698.33	360.62	188831.64	12.20	1082.86	185.53	263658.03	0.79	3484.80	50.66
TOTAL	89986.84	1.00	21256.24	470.07	271007.61	72.29	1343.89	200.60	499658.71	1.16	6742.53	316.32

Table 2. (continued...)

	Sampling Year 1997				Sampling Year 1998				Sampling Year 1999			
Area	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group
Inshore												
CB	18101.30	0.09	15.15	0.67	16203.62	0.06	14.64	0.06	15323.49	1.11	3618.16	24.15
TB	13363.79	9.66	1676.25	241.96	1801.22	0.05	23.72	32.95	26131.84	6.65	11.02	0.00
BB	17749.19	5.52	3079.56	23.40	11630.7*	0.17*	20.06*	44.94*	61715.93	0.19	59.89	0.06
NDB	17034.09	2.65	2.00	0.91	30445.79	0.41	30.14	138.12	16813.33	7.64	4570.15	1.37
WB	23450.91	17.46	1022.81	1.03	14383.76	0.17	14.12	2.63	15636.53	0.31	128.70	0.66
SUM	89709.08	35.29	5795.79	267.97	76668.29	0.86	103.28	224.70	135619.12	17.90	8383.92	26.26
Offshore												
HB	0.00	0.00	0.00	0.39	4404.30	0.00	0.00	0.00	0.00	0.00	0.00	0.20
ISN	286.36	0.00	52.00	159.73	6041.34	0.00	1.98	11.16	0.00	1.64	532.48	21.45
ISS	76000.96	2.29	1.34	55.06	65324.17	0.00	66.54	2177.05	38482.34	2.03	1391.15	40.00
BIBI	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.06	0.00
BIBO												
FIBI	0.00	0.00	3.32	21.24	3500.74	0.20	408.09	85.65	5161.35	85.11	4480.24	418.20
FIBO												
NGB	12043.71	0.00	7502.06	667.89	11740.84	2.50	3922.34	5519.45	35619.72	277.92	2043.01	20.24
SA	21928.66	0.00	1126.22	0.00					3484.92	75.84	14.38	0.26
SGB	340.81	0.00	0.62	1.54	16549.69	0.00	58.25	108.64	617.51	0.00	36.52	1.47
NOSE	0.00	0.17	51.78	2.28	776.38	0.00	1638.66	165.44				
TAIL												
SGBO												
WD												
SUM	89571.88	2.29	7451.14	938.35	105215.78	2.70	4459.87	7959.90	80860.92	346.70	8493.46	537.46
TOTAL	179280.96	37.58	13246.93	1204.32	181884.07	3.56	4563.15	8184.60	216480.04	364.60	16877.38	563.72

Table 2. Abundance indices of Northwest Atlantic capelin (2J3KLNO) based on the two-ship surveys, 1994-1999, using the Weighted Index Area method (number m^{-3} 10^3 Bongo and 10^5 IYGPT). * - indicates estimated value, see text for details.

	Sampling Year 1994				Sampling Year 1995				Sampling Year 1996			
Area	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group
Inshore												
CB	7885.39	0.00	2151.19	89.54	27825.12	0.00	8.62	1.33	59170.22	0.00	0.42	0.21
TB	3797.05	0.00	258.49	11.19	13760.88	0.11	8.46	1.04	35682.76	0.00	24.29	6.50
BB	4615.81	0.00	1067.86	5.82	13439.82	0.39	7.74	1.36	37952.82	0.19	3216.23	249.38
NDB	18803.24	0.00	45.93	2.21	19478.80	59.47	234.63	6.19	45499.36	0.00	12.04	0.34
WB	17589.24	0.19	34.44	0.69	7671.55	0.12	1.58	5.15	57695.52	0.18	4.70	9.21
SUM	52870.73	0.19	3557.91	109.45	82175.97	60.09	261.03	15.07	236000.68	0.37	3257.73	265.64
Offshore												
HB					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISN					4311.18	0.98	0.00	17.57	0.00	0.00	0.16	0.16
ISS	28081.33	0.50	50.95	0.00	34173.79	0.00	14.64	5.16	196751.14	0.40	10.82	9.17
BIBI					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIBO												
FIBI					5805.14	0.00	8.31	5.71	3201.03	0.39	1798.45	7.65
FIBO												
NGB	9181.50	0.31	16834.73	275.27	143567.73	11.22	716.02	144.38	63705.86	0.00	1675.37	33.70
SA	8064.32	0.00	219.38	63.95					14021.44	0.00	16.95	0.48
SGB	53.26	0.00	812.65	85.35	973.80	0.00	341.09	12.71	0.00	0.00	0.00	0.00
NOSE									0.00	0.00	606.74	0.66
TAIL												
SGBO												
WD												
SUM	37316.11	0.81	17698.33	360.62	188831.64	12.20	1082.86	185.53	263658.03	0.79	3484.80	50.68
TOTAL	89986.84	1.00	21256.24	470.07	271007.61	72.29	1343.89	200.60	499658.71	1.16	6742.53	316.32

Table 2. (continued...)

	Sampling Year 1997				Sampling Year 1998				Sampling Year 1999			
Area	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group	0-Group Bongo	0-Group IYGPT	1-Group	2+-Group
Inshore												
CB	18101.30	0.00	15.18	0.67	16203.82	0.06	14.64	6.06	15323.49	1.11	3613.16	24.15
TB	13363.79	9.86	1676.25	241.98	1801.22	0.05	23.72	32.95	26131.84	8.65	11.02	0.00
BB	17749.19	5.52	3079.55	23.40	11830.7*	0.17*	20.66*	44.94*	61713.93	0.19	59.89	0.08
NDB	17034.69	2.85	2.00	0.91	30448.79	0.41	30.14	138.12	16813.33	7.84	4570.15	1.37
WB	23459.91	17.46	1022.81	1.03	14383.76	0.17	14.12	2.63	15636.53	0.31	129.70	0.66
SUM	89709.08	35.29	5795.79	267.97	76668.29	0.86	103.28	224.70	135619.12	17.90	8383.92	26.26
Offshore												
HB	0.00	0.00	0.00	0.39	4404.30	0.00	0.00	0.00	0.00	0.00	0.00	0.20
ISN	286.38	0.00	52.80	159.73	8041.34	0.00	1.66	11.16	0.00	1.64	532.48	21.45
ISS	76000.96	2.29	1.34	85.95	65324.17	0.00	66.54	2177.05	38462.34	2.03	1391.15	40.00
BIBI	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.06	0.00
BIBO												
FIBI	0.00	0.00	3.32	21.24	5560.74	0.20	408.08	85.60	5161.35	65.11	4480.24	448.20
FIBO												
NGB	12943.71	0.00	7392.66	667.89	11740.84	2.50	3922.34	5519.45	38619.72	277.92	2043.01	26.34
SA	21928.66	0.00	1126.22	0.00					3484.92	75.84	14.38	0.26
SGB	340.81	0.00	0.62	1.54	16548.69	0.00	59.25	166.64	617.51	0.00	36.52	1.47
NOSE	0.00	0.17	51.78	2.28	776.38	0.00	1638.66	165.44				
TAIL												
SGBO												
WD												
SUM	89571.88	2.29	7451.14	936.35	105215.78	2.70	4459.87	7959.90	80860.92	346.70	8493.46	537.46
TOTAL	179280.96	37.58	13246.93	1204.32	181884.07	3.56	4563.15	8184.60	216480.04	364.60	16877.38	563.72

Table 3. Abundance indices adjusted for night/day differences of for Northwest Atlantic capelin (2J3KLNO) based on the two-ship surveys, 1994-1999, using the Weighted Index Area method (number m^{-3} 10^3 Bongo and 10^5 IYGPT). * - indicates estimated value, see text for details.

	Sampling Year 1997				Sampling Year 1998				Sampling Year 1999			
Area	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group
Inshore												
CB	18101.39	0.00	15.18	0.67	18203.87	0.06	8.36	2.44	15323.52	1.11	3613.18	17.00
TB	13363.66	9.66	1676.20	241.35	1801.23	0.05	8.76	3.90	28131.83	4.41	2.16	0.00
BB	17749.11	0.27	1619.62	8.07	11830.7*	0.15*	15.08*	27.80*	61713.89	0.08	16.51	0.08
NDB	17034.98	0.58	2.00	0.48	30448.79	0.41	29.84	101.41	16813.15	3.42	97.42	0.97
WB	23459.99	17.46	1022.71	0.59	14383.69	0.09	13.34	2.63	15636.43	0.18	53.43	0.49
SUM	89709.13	27.97	4335.71	251.16	76668.29	0.76	75.38	137.98	135618.82	9.20	3782.68	18.54
Offshore												
HB	0.00	0.00	0.00	0.39	4404.27	0.00	0.00	0.00	0.00	0.00	0.00	0.20
ISN	286.46	0.00	27.64	55.08	6041.57	0.00	1.66	7.17	0.00	0.68	516.28	15.16
ISS	76001.02	2.29	0.89	85.95	65323.84	0.00	67.28	2157.89	38462.16	1.73	1238.70	28.64
BIBI	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00
BIBO												
FIBI	0.00	0.00	3.32	21.24	5561.07	0.20	357.53	8.76	5161.23	65.11	134.80	371.32
FIBO												
NGB	12943.87	0.00	7117.45	494.74	11741.37	2.16	3018.02	3254.46	36619.84	195.69	1598.83	18.55
SA	21928.65	0.00	1126.03	0.00					3485.11	31.34	14.38	0.18
SGB	340.83	0.00	0.43	1.54	16548.80	0.00	15.42	9.46	617.66	0.00	18.21	1.04
NOSE	0.00	0.17	51.43	1.92	776.52	0.00	1601.55	91.90				
TAIL												
SGBO												
WD												
SUM	89572.18	2.29	7149.93	658.55	105216.65	2.36	3459.91	5437.76	80860.89	263.21	3507.21	434.71
TOTAL	179281.31	30.26	11485.64	909.71	181884.94	3.12	3535.29	5575.74	216479.71	272.41	7289.89	453.25

Table 3. (continued...)

	Sampling Year 1994				Sampling Year 1995				Sampling Year 1996			
Area	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group
Inshore												
CB	7865.34	0.00	2151.19	89.54	27825.09	0.00	3.33	0.28	59170.29	0.00	0.42	0.21
TB	3796.99	0.00	248.35	11.19	13760.81	0.11	6.80	0.18	35682.86	0.00	24.29	4.62
BB	4615.73	0.00	1067.86	5.22	13439.94	0.09	7.74	1.60	37952.85	0.09	3216.28	248.31
NDB	18803.16	0.00	38.19	1.39	19478.79	38.79	230.60	6.19	45499.30	0.00	1.10	0.34
WB	17589.26	0.19	10.02	0.06	7671.45	0.12	1.39	2.63	57695.33	0.09	0.18	0.72
SUM	52670.48	0.19	3513.61	107.40	82176.08	39.11	249.86	10.88	236000.43	0.18	3242.27	254.20
Offshore												
HB					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISN					4311.25	0.25	0.00	11.87	0.00	0.00	0.16	0.16
ISS	28080.99	0.50	23.85	0.00	34173.86	0.00	14.64	5.16	196751.12	0.40	0.42	9.17
BIBI					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIBO												
FIBI					5805.49	0.00	8.31	3.85	3200.62	0.39	92.39	0.97
FIBO												
NGB	9181.83	0.31	4192.09	121.69	143567.83	2.94	699.07	115.59	63706.31	0.00	1003.84	23.82
SA	8064.13	0.00	219.38	63.95					14021.44	0.00	8.69	0.48
SGB	53.15	0.00	119.66	8.89	973.97	0.00	132.68	3.33	0.00	0.00	0.00	0.00
NOSE									0.00	0.00	199.60	0.66
TAIL												
SGBO												
WD												
SUM	37315.77	0.81	4335.70	130.58	188832.40	3.19	854.70	139.60	263658.05	0.79	1096.81	34.12
TOTAL	89986.25	1.00	7849.31	237.98	271008.48	42.30	1104.56	150.48	499658.48	0.97	4339.08	288.32

Table 3. Abundance indices adjusted for night/day differences of for Northwest Atlantic capelin (2J3KLNO) based on the two-ship surveys, 1994-1999, using the Weighted Index Area method (number m^{-3} 10^3 Bongo and 10^5 IYGPT). * - indicates estimated value, see text for details.

	Sampling Year 1997				Sampling Year 1998				Sampling Year 1999			
Area	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group
Inshore												
CB	18101.39	0.00	15.18	0.87	16203.87	0.06	3.36	2.44	15323.52	1.11	3613.16	17.00
TB	19383.86	9.66	1676.20	241.35	1801.23	0.05	6.76	3.90	26131.83	4.41	2.16	0.00
BB	17749.11	0.27	1619.62	8.07	11630.7*	0.15*	15.06*	27.60*	61713.69	0.08	18.51	0.08
NDB	17034.96	0.58	2.00	0.48	30448.79	0.41	29.64	101.41	16813.15	3.42	97.42	0.97
WB	23459.99	17.46	1022.71	0.59	14383.69	0.09	13.34	2.63	15636.43	0.18	53.43	0.49
SUM	89709.13	27.97	4335.71	251.16	76668.29	0.76	75.38	137.98	135618.82	9.20	3782.68	18.54
Offshore												
HB	0.00	0.00	0.00	0.39	4404.27	0.00	0.00	0.00	0.00	0.00	0.00	0.20
ISN	266.46	0.00	27.64	55.08	6041.57	0.00	1.66	7.17	0.00	0.68	516.28	15.16
ISS	76001.02	2.29	0.69	96.95	65323.84	0.00	67.28	2157.89	39462.16	1.73	1236.70	26.64
BIBI	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00
BIBO												
FIBI	0.00	0.00	3.32	21.24	5561.07	0.20	357.53	8.76	5181.23	65.11	134.00	371.32
FIBO												
NGB	12943.57	0.00	7117.45	494.74	11741.37	2.18	3018.02	3254.40	32619.84	196.69	1598.63	18.65
SA	21928.65	0.00	1126.03	0.00					3485.11	31.34	14.38	0.18
SGB	340.63	0.00	0.43	1.54	16548.60	0.00	15.42	9.46	617.05	0.00	18.21	1.04
NOSE	0.00	0.17	51.43	1.92	776.52	0.00	1601.55	91.90				
TAIL												
SGBO												
WD												
SUM	89572.18	2.29	7149.93	658.55	105216.65	2.38	3459.91	5437.76	80660.89	263.21	3507.21	434.71
TOTAL	179281.31	30.26	11485.64	909.71	181884.94	3.12	3535.29	5575.74	216479.71	272.41	7289.89	453.25

Table 3. (continued...)

	Sampling Year 1994				Sampling Year 1995				Sampling Year 1996			
Area	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group	0-Group B	0-Group I	1-Group	2+-Group
Inshore												
CB	7665.34	0.00	2151.19	80.54	27825.00	0.00	3.33	0.26	59170.29	0.00	0.42	0.21
TB	3796.99	0.00	246.35	11.19	13760.61	0.11	6.80	0.18	35682.66	0.00	24.29	4.62
BB	4615.73	0.00	1067.86	5.22	13439.94	0.09	7.74	1.60	37952.65	0.09	3216.28	248.31
NDB	18803.16	0.00	35.19	1.39	19478.79	38.79	230.60	6.19	45499.30	0.00	1.10	0.34
WB	17589.26	0.19	10.02	0.06	7671.45	0.12	1.39	2.63	57695.33	0.09	0.18	0.72
SUM	52670.48	0.19	3513.61	107.40	82176.08	39.11	249.86	10.88	236000.43	0.18	3242.27	254.20
Offshore												
HB					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISN					4311.25	0.25	0.00	11.67	0.00	0.00	0.16	0.16
ISS	28060.90	0.50	25.65	0.00	34173.86	0.00	14.64	5.16	196751.12	0.40	0.42	9.17
BIBI					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIBO												
FIBI					5805.49	0.00	8.31	3.86	3200.62	0.39	92.39	0.97
FIBO												
NGB	9181.03	0.31	4102.09	121.69	143567.63	2.94	899.07	115.59	69700.31	0.00	1903.54	23.82
SA	8064.13	0.00	219.38	63.95					14021.44	0.00	8.69	0.48
SGB	53.15	0.00	119.00	8.68	973.97	0.00	122.68	3.33	0.00	0.00	0.00	0.00
NOSE									0.00	0.00	199.60	0.66
TAIL												
SGBO												
WD												
SUM	37315.77	0.81	4335.70	130.58	188832.40	3.19	854.70	139.60	263658.05	0.79	1096.81	34.12
TOTAL	89986.25	1.00	7849.31	237.98	271008.48	42.30	1104.56	150.48	499658.48	0.97	4339.08	288.32

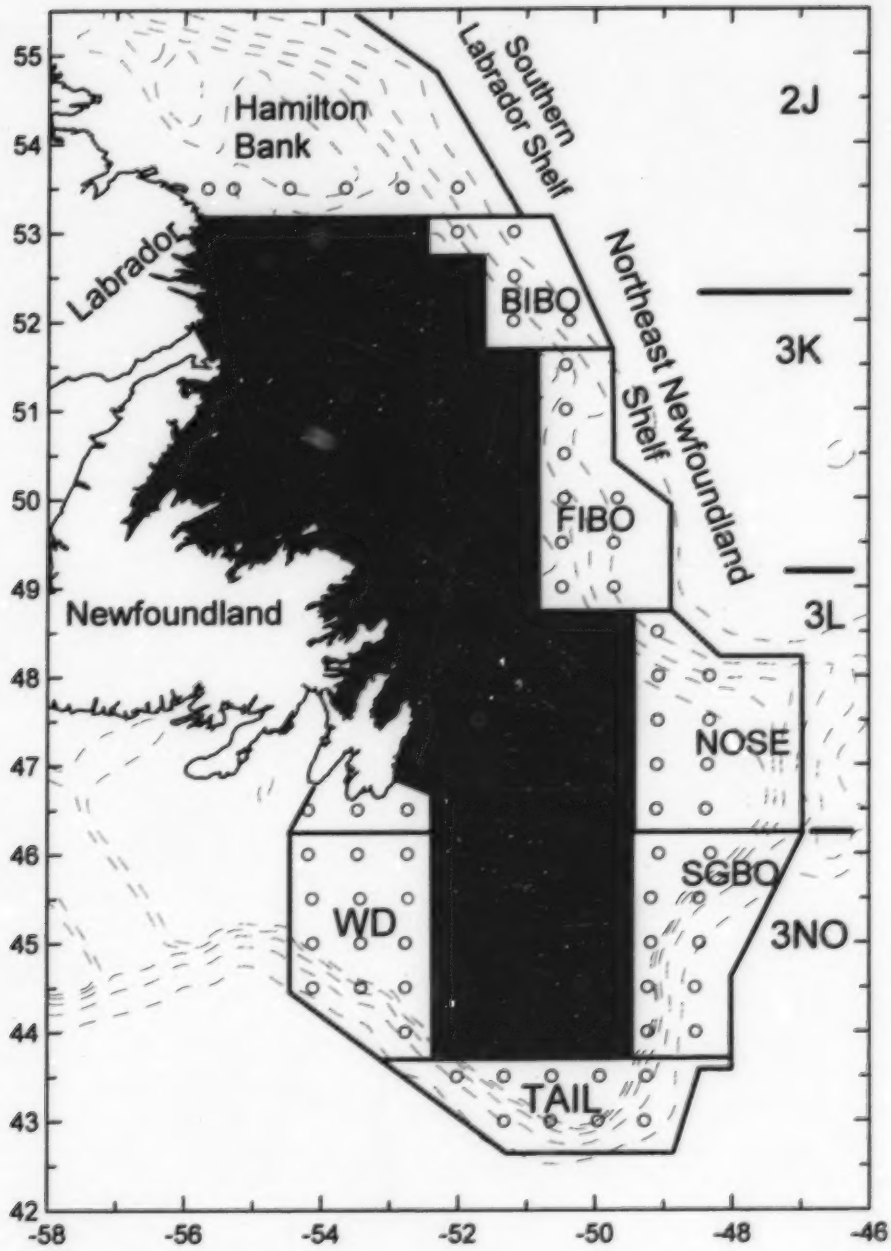

Figure 1. Pelagic Juvenile Fish Survey area, showing sample locations (indicated by 'o') and Index Areas. The shaded areas represent the Index Areas used in the calculation of annual abundance indices.

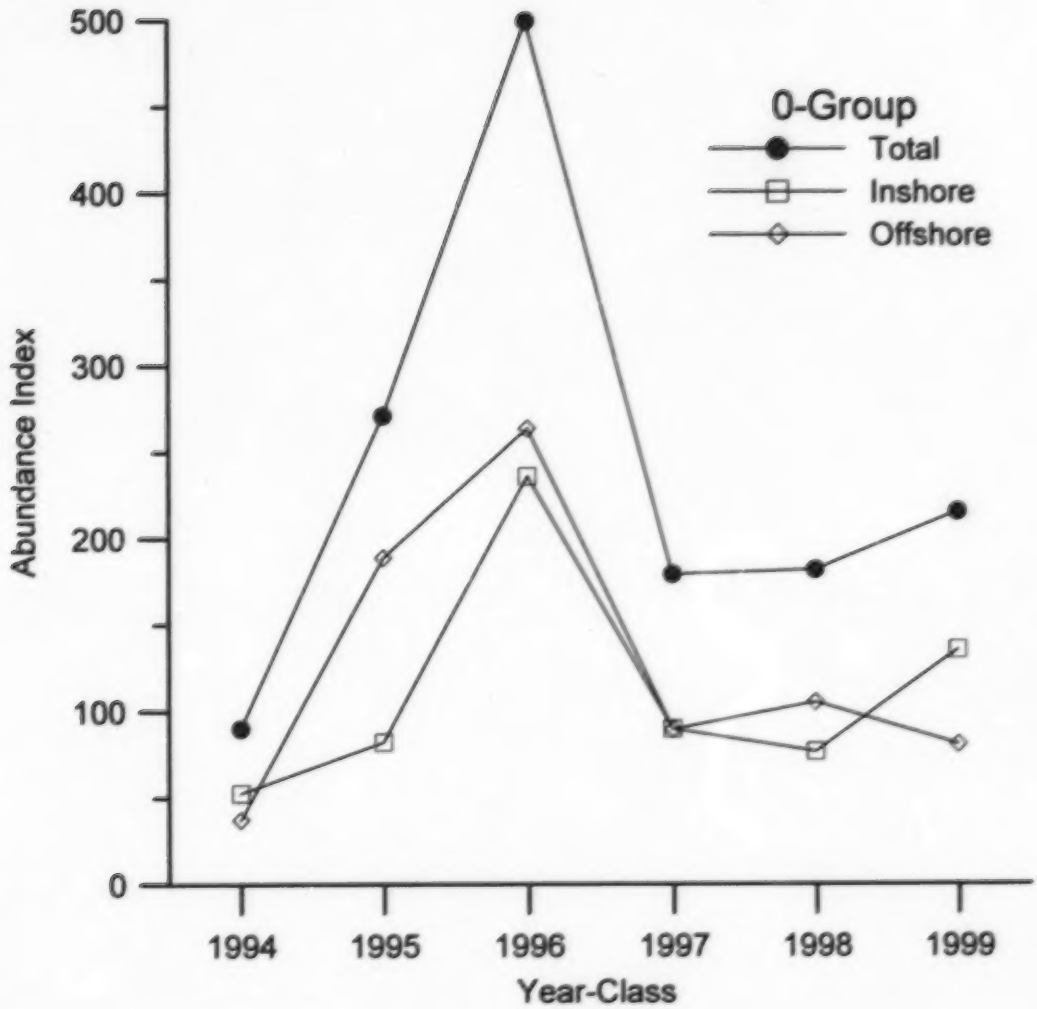

Figure 2. Year-class abundance index for 0-group (larval) capelin for inshore, offshore and both areas combined, 1994-1999 based on night/day corrections.

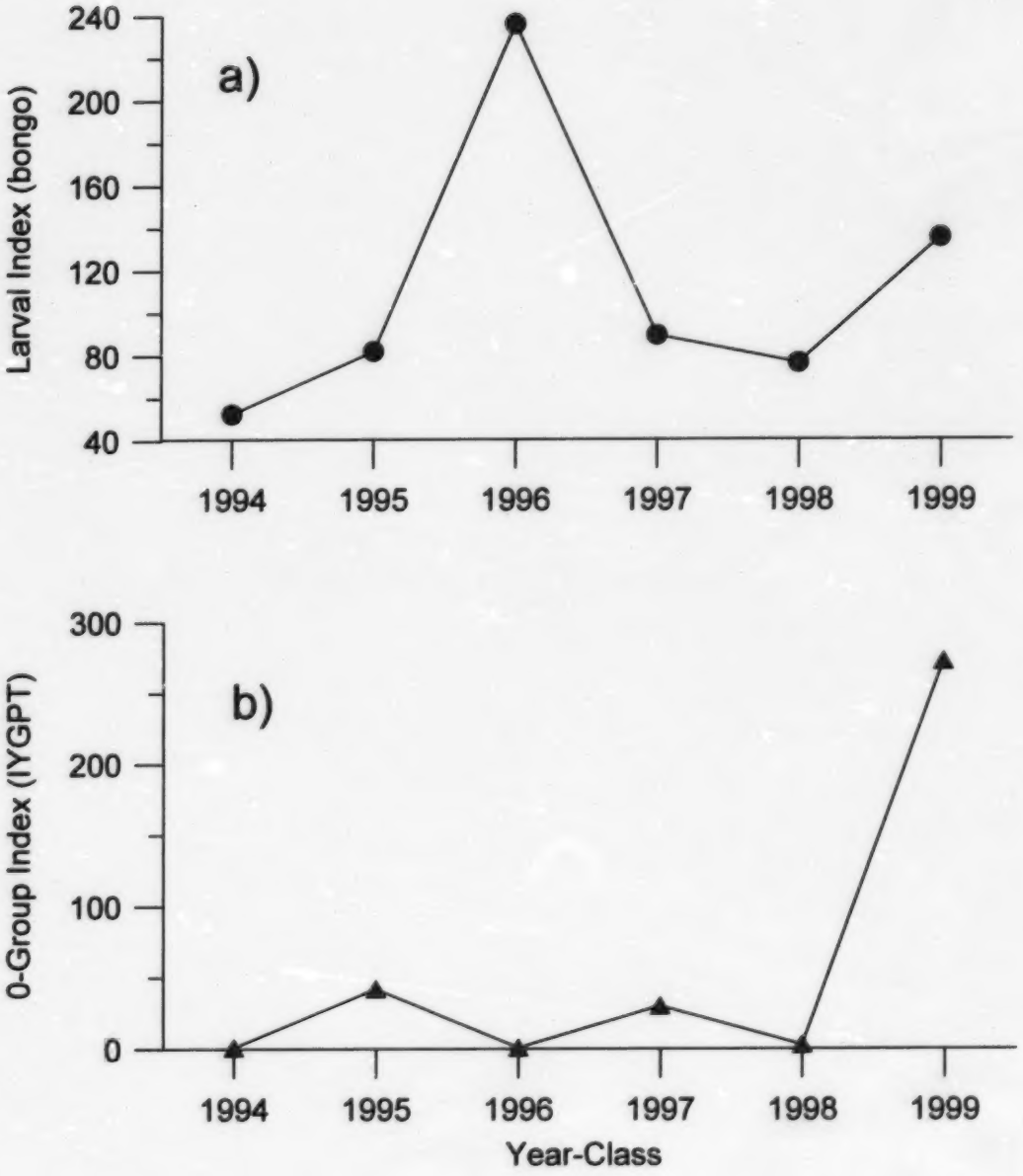

Figure 3. Year-class abundance indices for (a) larval capelin captured in the bongo and b) 0-group capelin captured in the IYGPT. Each index is based on the Weighted Index Area method for night/day corrected data and both indices are considered relative within each time series.

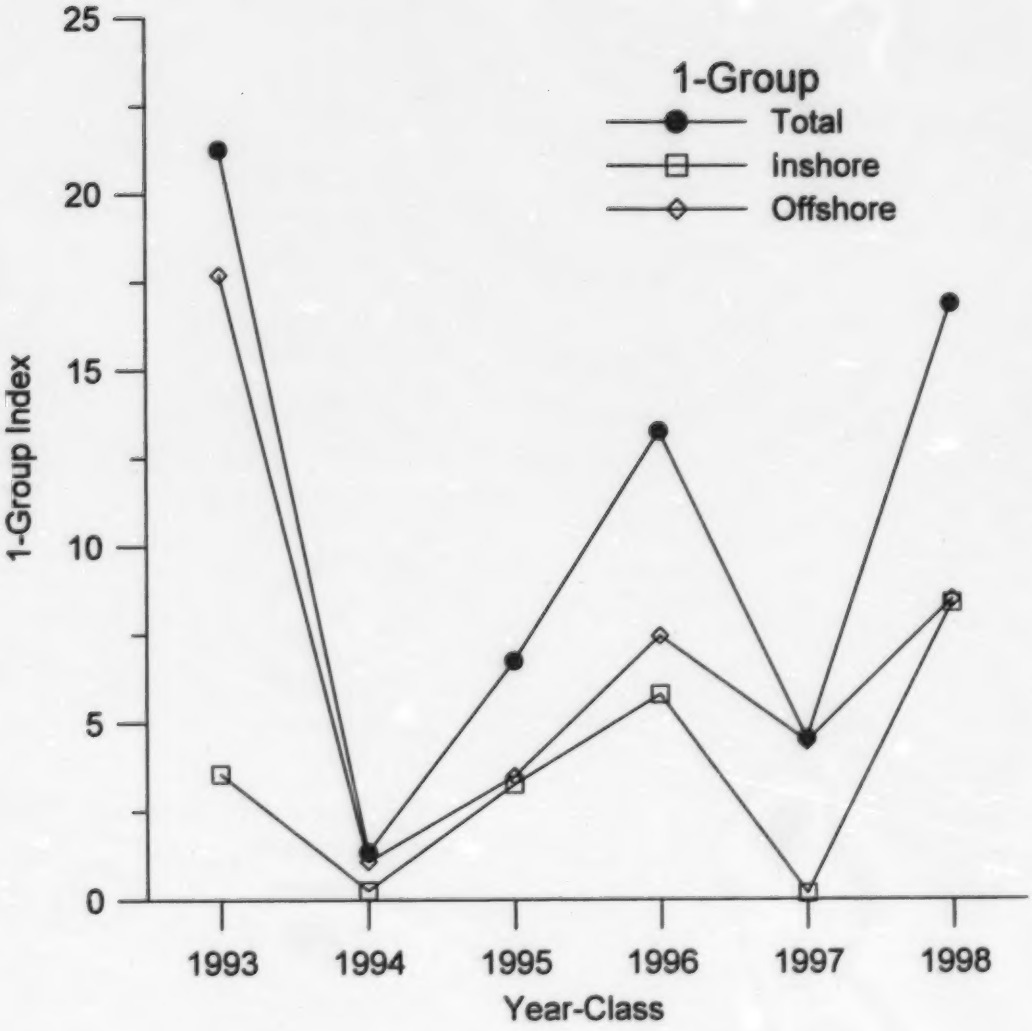

Figure 4. Year-class abundance indices for 1-group capelin sampled inshore, offshore and both areas combined.

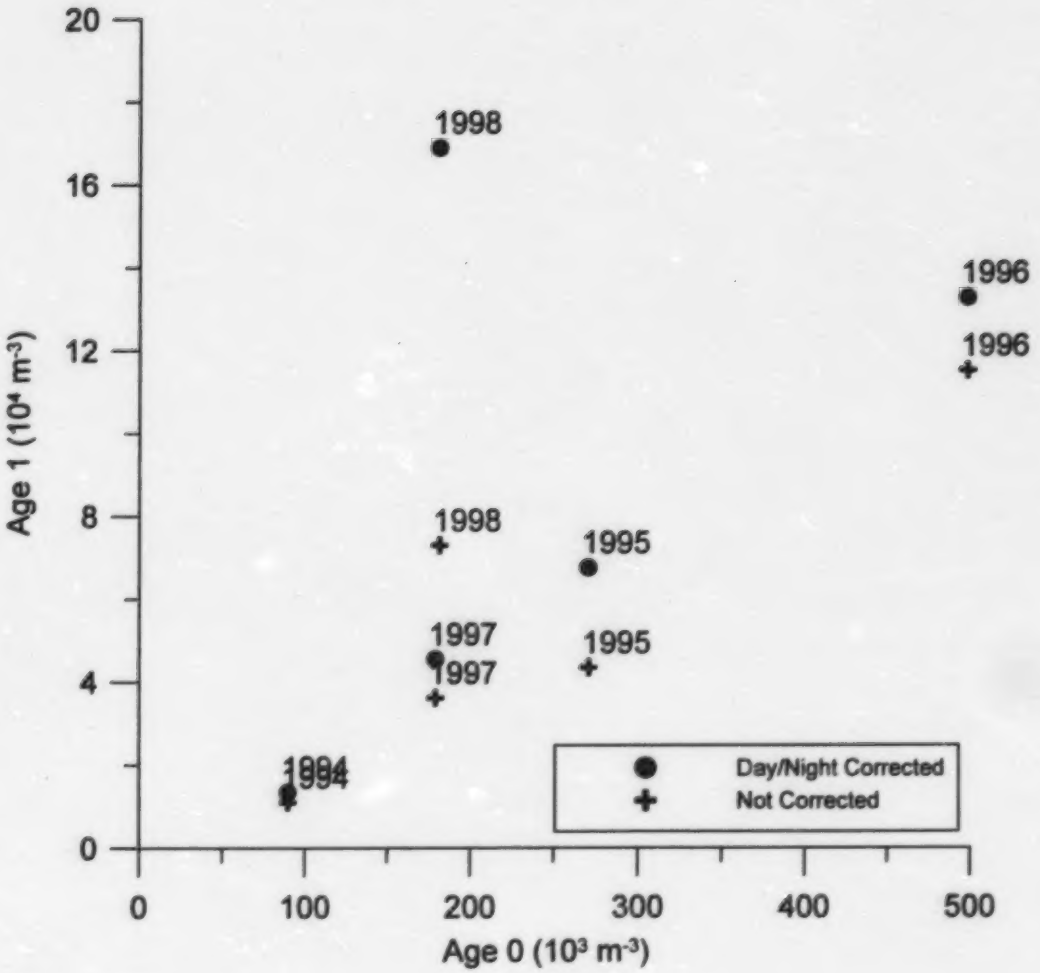

Figure 5. Year-class abundance indices for 0-group (larval) and 1-group capelin. The data point labels reference year-class.

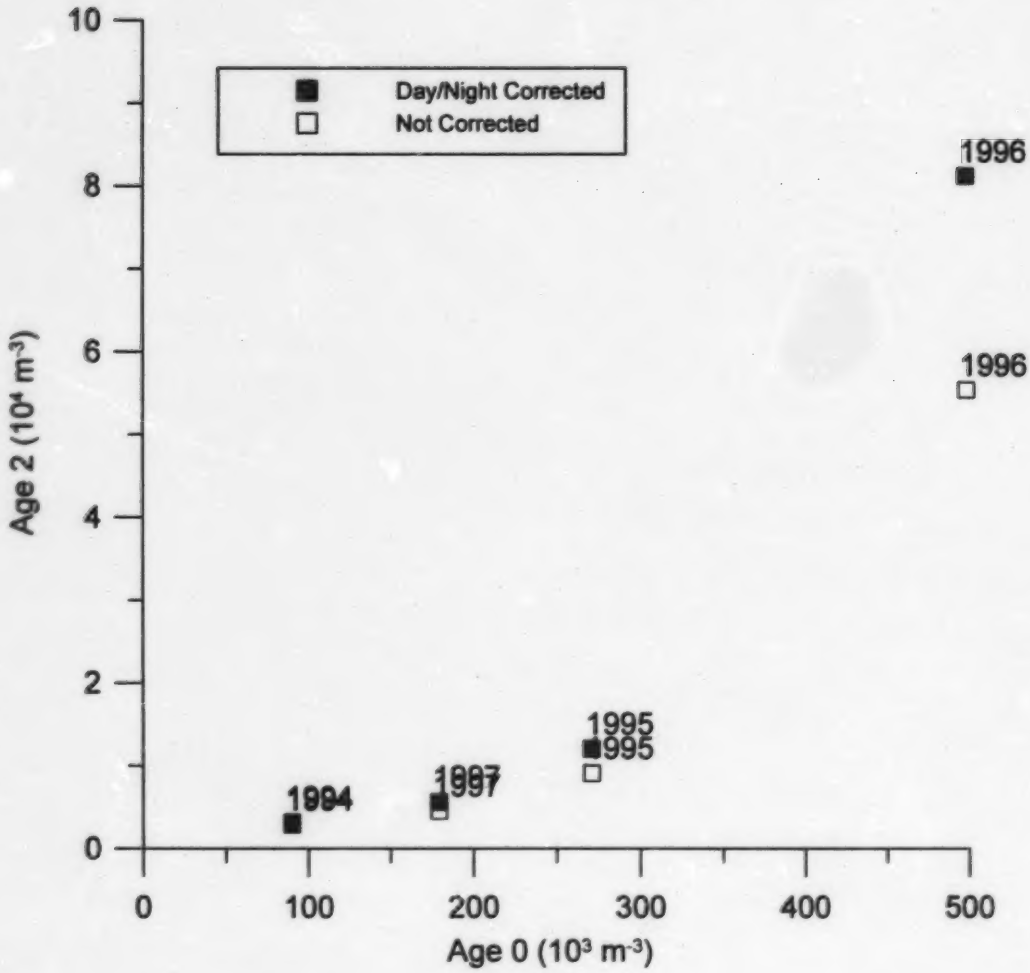

Figure 6. Year-class abundance indices for 0-group (larval) and 2-group capelin. The data point labels reference year-class.

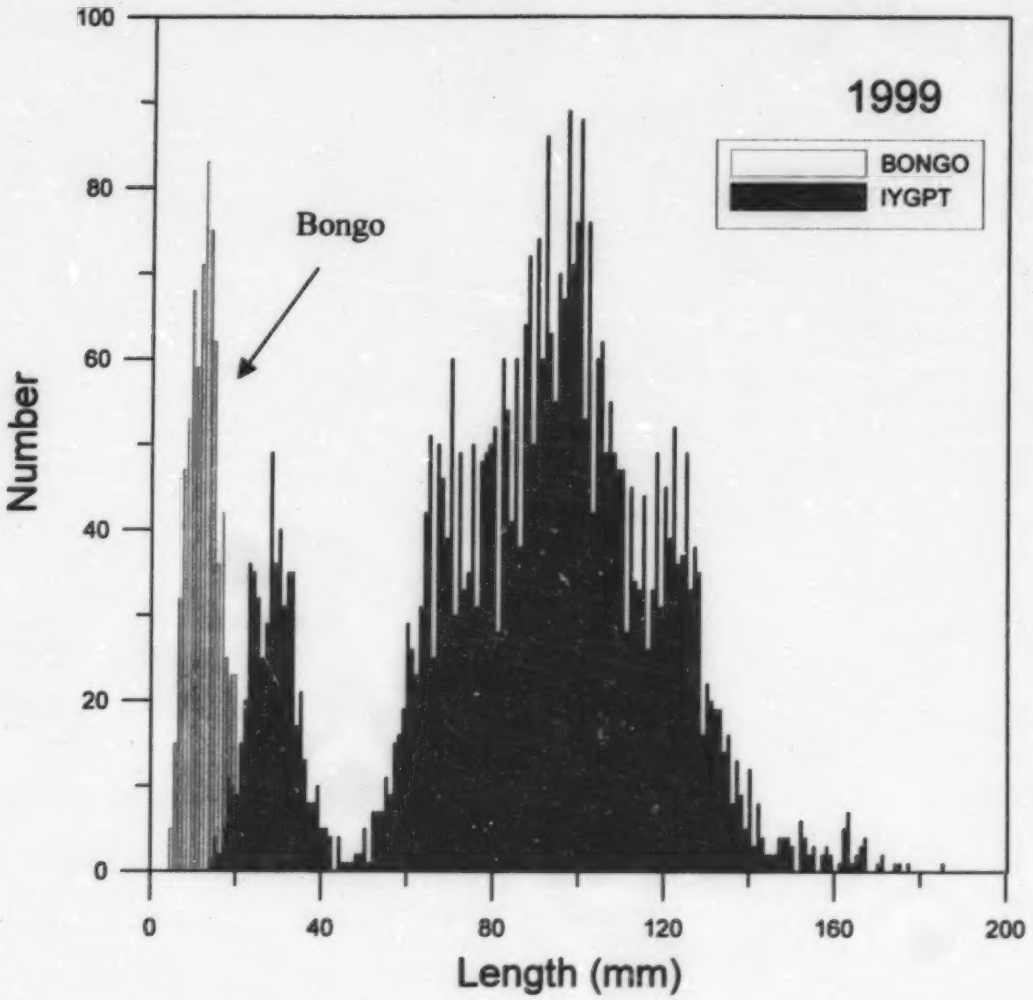

Figure 7. Length frequency distributions from the bongo and IYGPT samplers in 1999.

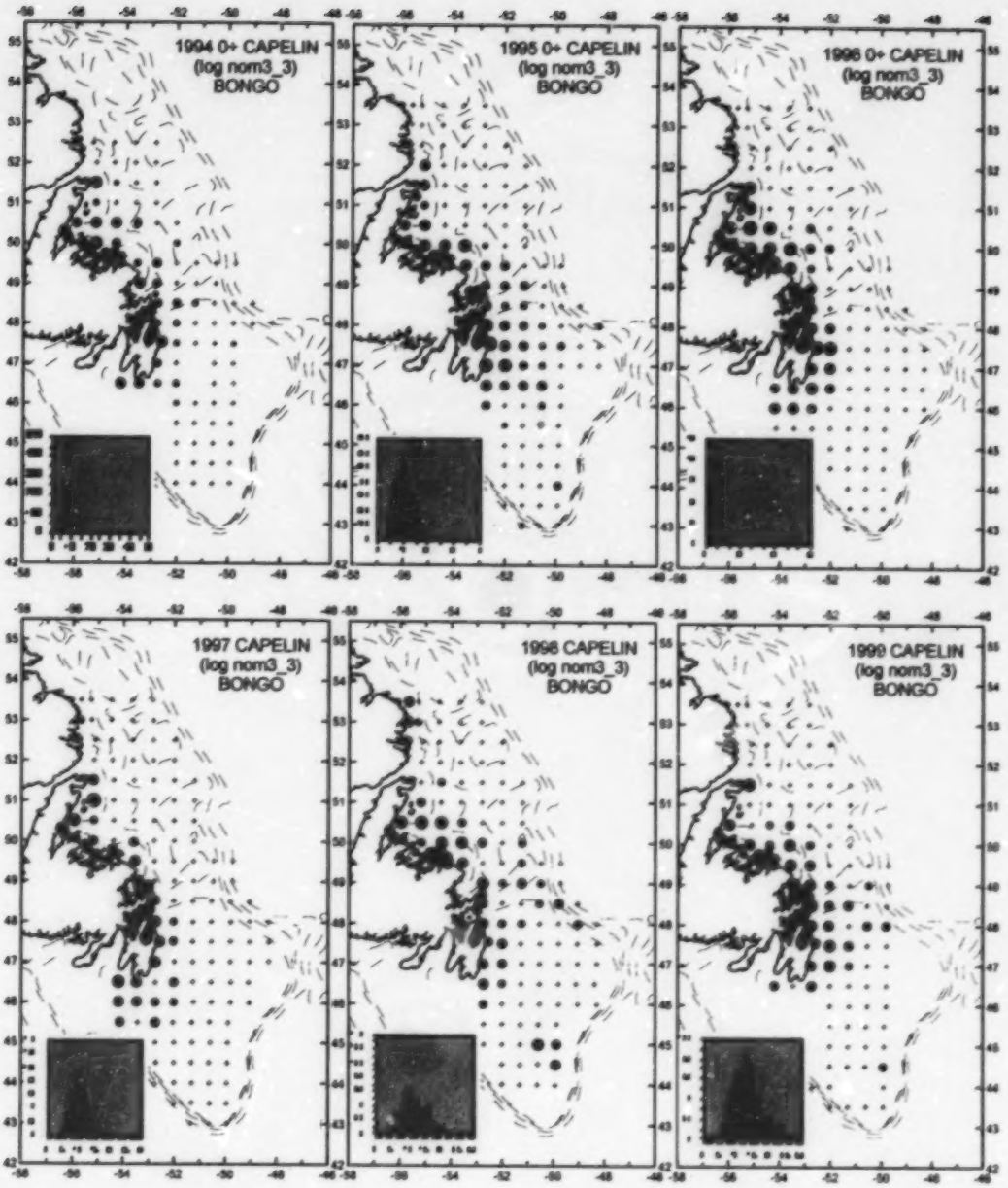

Figure 8. Distribution of larval capelin sampled by the bongo 1994-1999. Abundance (log_{10} number m^{-3}) at each station is represented by an expanding symbol, where values were standardized to a common scale among years. Crosses (+) represent stations where capelin were not caught.

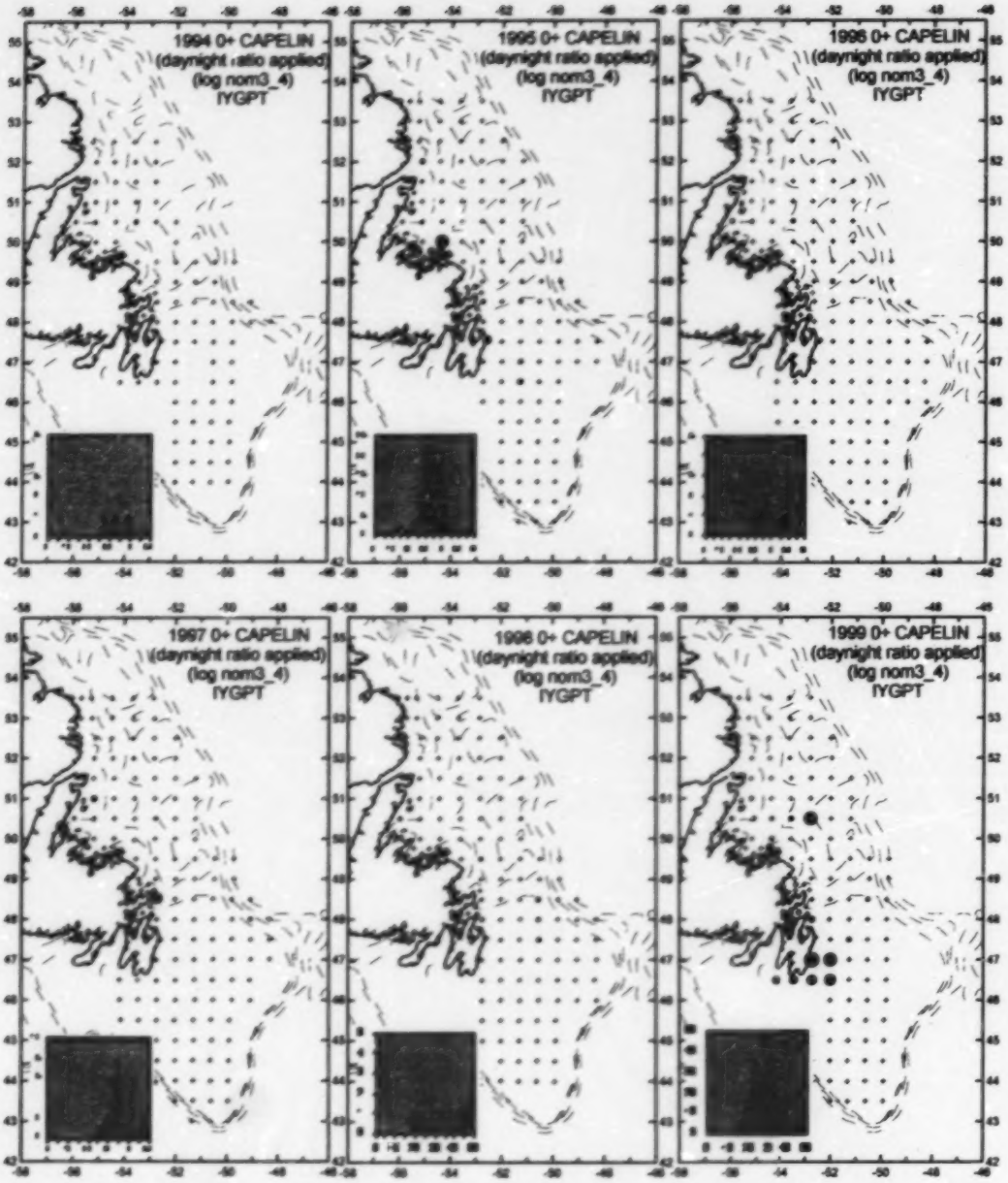

Figure 9. Distribution of 0-group capelin sampled by the IYGPT 1994-1999. Abundance ($\log_{10}$ number m^{-3}) at each station is represented by an expanding symbol, where values were standardized to a common scale among years. Crosses (+) represent stations where capelin were not caught.

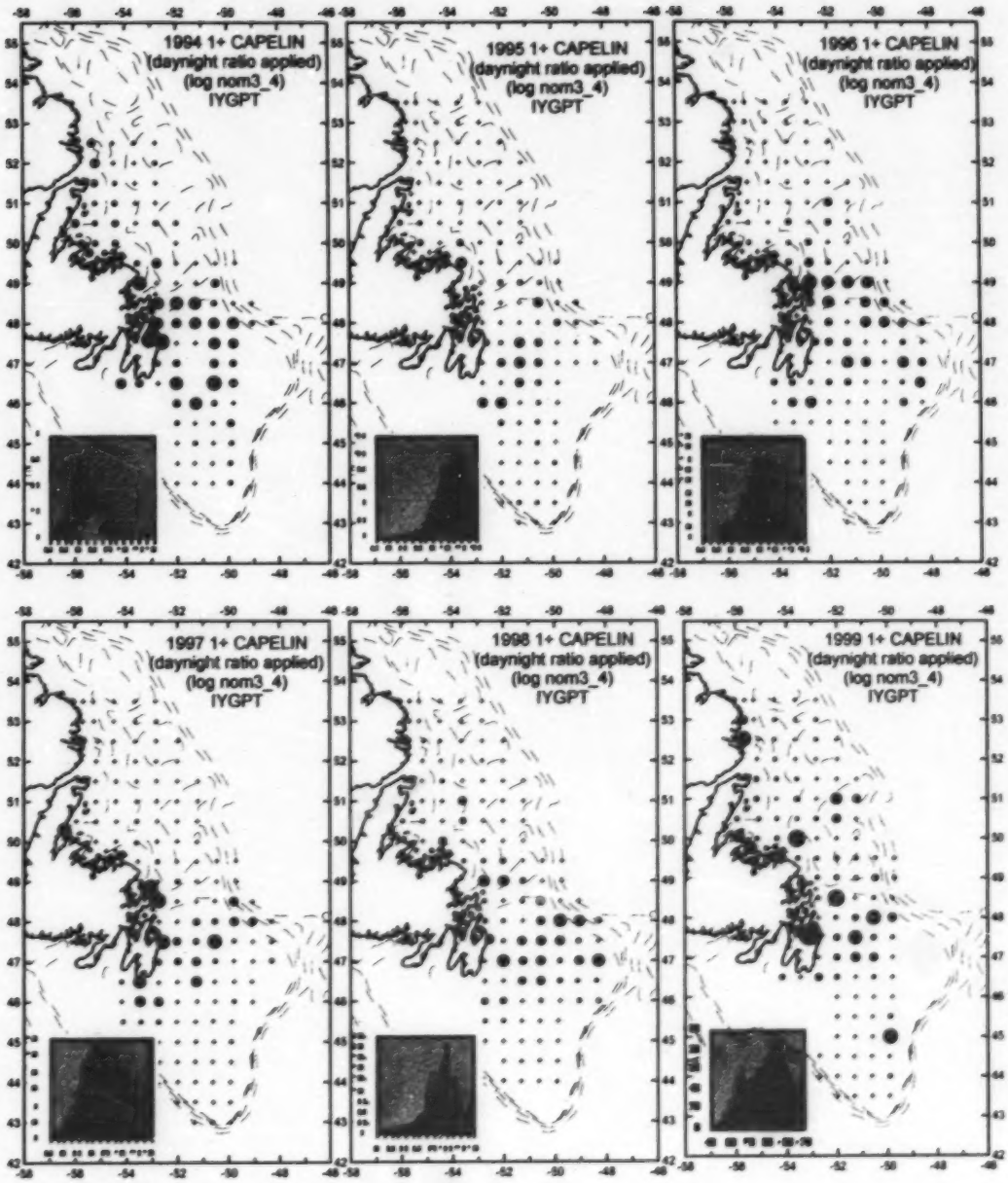

Figure 10. Distribution of 1-group capelin sampled by the IYGPT 1994-1999. Abundance (log_{10} number m^{-2}) at each station is represented by an expanding symbol, where values were standardized to a common scale among years. Crosses (+) represent stations where capelin were not caught.

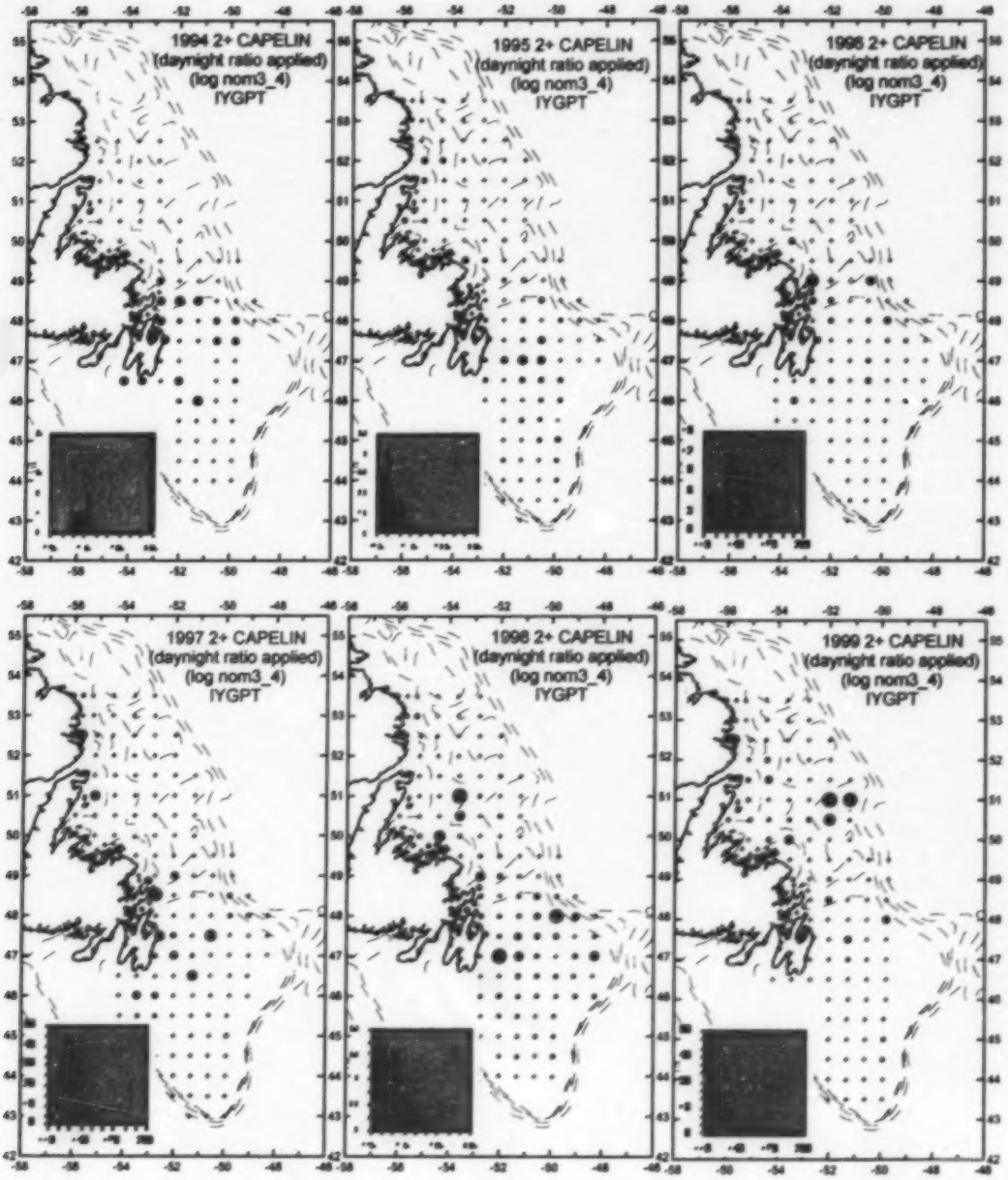

Figure 11. Distribution of 2-group capelin sampled by the IYGPT 1994-1999. Abundance (log_{10} number m^{-3}) at each station is represented by an expanding symbol, where values were standardized to a common scale among years. Crosses (+) represent stations where capelin were not caught.